Synergistic Effects of Hydrogel Application and Mulching Practices for Climate-Resilient Pearl Millet (*Pennisetum glaucum* L.) Production

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ABSTRACT

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| **Aim:** This study aimed to evaluate the effects of hydrogel application and mulching on the physiological growth attributes and yield, of pearl millet (*Pennisetum glaucum* L.) under semi-arid conditions.**Study design:** The experiment was conducted using a factorial randomized block design with twelve treatment combinations, including different hydrogel application rates (2.5 kg ha-1, 5 kg ha-1 and 7.5 kg ha-1) in combination with mulching types (paddy straw, polythene, and no mulching).**Place and Duration of Study:** The field experiment was conducted at the instructional farm of the School of Agricultural Sciences, Karunya Institute of Technology and Science, Coimbatore, during the kharif 2024-25 cropping season.**Methodology:** Pearl millet variety CO 10 was used with a seed rate of 5 kg ha-1. The crop was transplanted 18 days after sowing, following the standard agronomic practices. The physiological attributes measured included leaf area index (LAI), crop growth rate (CGR), and net assimilation rate (NAR). The grain yield was recorded at harvest. Statistical analysis was performed using ANOVA to determine treatment effects.**Results:** The results indicated that the application of hydrogel at 5 kg ha-1 with polythene mulching significantly improved the yield of pearl millet crop by registering a higher yield of 24.40 q ha-1 while positively impacting the all thephysiological parameters of crop growth. **Conclusion:** The integration of hydrogel and mulching significantly enhanced pearl millet growth and yield. This suggest that hydrogel and mulching can be an effective strategies for sustainable pearl millet production in water-limited environments. Future research should explore long-term effects and economic feasibility for large-scale adoption. |

***Keywords:*** *Pearl millet, Hydrogel application, Mulching, Drought mitigation, Crop growth rate.*

1. INTRODUCTIOn

Pearl millet (*Pennisetum glaucum* L.) is an important cereal crop grown in the arid and the semi-arid regions of the world due to its remarkable drought tolerance and ability to thrive in nutrient-deficient soils. It serves as a staple food for millions, offering high energy content and vital nutrients[1]. However, erratic rainfall and water scarcity remain significant challenges, necessitating sustainable water management strategies[2]. Hydrogel application and mulching have emerged as promising techniques for enhancing soil moisture retention, reducing water loss, and improving crop growth and yield[3]. Hydrogels, being a superabsorbent polymer, it significantly improves the soil water-holding capacity and reduce the irrigation requirements[4]. Similarly, mulching aids in reducing the soil temperature fluctuations, suppressing the weeds, and conserving the moisture [5]. Research indicates that hydrogel application at the rate of 5 kg/ha significantly enhances the plant height, biomass accumulation, and grain yield[3]. Furthermore, studies on genotype-by-environment interactions have shown that pearl millet hybrids respond differently to mulching and hydrogel application, highlighting the need for location-specific agronomic practices[6]. The effectiveness of mulching also depends on the type of material used. Studies have found that mustard straw mulch application at the rate of 2.5 t/ha significantly improved the soil moisture retention and pearl millet productivity[7]. Other researches have demonstrated that mulching can play a role in modifying the soil microclimate, leading to improved water-use efficiency[8]. In addition to improving soil moisture conservation, hydrogel and mulching also enhance the soil microbial activity, and promoting better nutrient uptake[9]. Research have also indicated that the combination of hydrogel and mulching positively impacts root structure, leading to better water absorption[10]. This study has evaluated the combined effects of hydrogel and mulching practices on the agronomic traits of pearl millet, with a focus on plant growth, yield and water-use efficiency. The findings will contribute to the development of climate-resilient agronomic practices for sustainable pearl millet production.

2. material and methods

A field experiment was conducted at the instructional farm of the School of Agricultural Sciences, Karunya Institute of Technology and Science, Coimbatore. The farm is located at 10.935° N latitude and 76.75° E longitude, at an elevation of 467 meters above sea level. The soil in this area is clay loam, with moderate levels of available nutrients of 232.91 kg/ha of nitrogen, 17.31 kg/ha of phosphorus, and 273.45 kg/ha of potassium. The soil has a slightly alkaline pH of 7.65 and a relatively high organic carbon content of 0.61%. During the crop growth period, the total rainfall recorded was 523.84 mm. The average temperature ranged from a high of 29.80°C to a low of 18.38°C. The relative humidity varied between 90.19% at its peak and 82.65% at its lowest.

**Table 1: Treatment details**

|  |  |
| --- | --- |
| **A Factor (Hydrogel)** | **Application** |
| H1 | No hydrogel |
| H2 | Hydrogel @ 2.5 kg ha-1 |
| H3 | Hydrogel @ 5 kg ha-1 |
| H4 | Hydrogel @ 7.5 kg ha-1 |
| **B Factor (Mulching)** | **Application** |
| M1 | No mulching |
| M2 | Paddy straw mulching |
| M3 | Polythene mulching |

The experiment followed a Factorial Randomized Glock Design (FRBD) with two factors viz hydrogel and mulching. The factor hydrogel comprises of four treatments namely No hydrogel(H1), Hydrogel @ 2.5 kg ha-1 (H2), Hydrogel @ 5 kg ha-1 (H3) and Hydrogel @ 7.5 kg ha-1 (H4). Similarly, the factor mulching had three treatment which includes No mulching (M1), Paddy straw mulching (M2) and polythene mulching (M3). Pusa Hydrogel, a super absorbent polymer developed by the Indian Agricultural Research Institute (IARI) was used for the study. It is a semi-synthetic, cross-linked material made from derivatized cellulose-grafted-anionic polyacrylate. Pearl millet variety CO 10 was selected for the experiment. The seeds were obtained from the Department of Millets, Tamil Nadu Agricultural University, and sown at the rate of 5 kg per hectare. The seedlings were first raised in a nursery bed and later 18 day old seedlings were transplanted into the main field, following a spacing of 45 × 15 cm. To ensure proper nutrition, 70 kg of nitrogen, 35 kg of phosphorus (P₂O₅), and 35 kg of potassium (K₂O) per hectare were applied. The entire phosphorus and potassium doses, along with half of the nitrogen, were applied before planting as a basal dose. The remaining nitrogen was top-dressed in two stages at 15 days and 30 days after transplanting (DAT). Key physiological growth parameters, including the leaf area index (LAI), crop growth rate (CGR) and net assimilation rate (NAR) were measured throughout the experiment using standard scientific methods.

**Leaf Area Index (LAI):** The Leaf Area Index (LAI) was calculated as the ratio of leaf area to ground area, using the formula proposed by Balakrishnan et al. (2008)[11].

LAI = $\frac{Leaf Area}{Ground Area (m^{2})}$

where,

Leaf Area = *L × B × N × K*

L = Leaf length

B = Leaf breadth

N = Number of leaves

K = Constant factor (0.75)

**Crop Growth Rate (CGR):** Crop Growth Rate (CGR) measures the rate of increase in dry weight per unit area over time and was calculated using the formula by Watson (1952)[12].

CGR = $\frac{W\_{2}-W\_{1}}{P(t\_{2}-t\_{1})}$ ​​

where,

* W₁ & W₂ = Initial and final dry weights of plants (g)
* t₁ & t₂ = Time intervals (days)
* P = Ground area occupied by plants (m²)

**Net assimilation rate (NAR):** The Net Assimilation Rate (NAR) determines the efficiency of photosynthesis per unit leaf area and was calculated using the formula given by Williams (1946)[13]:

NAR = $\frac{(W\_{2}-W\_{1})(L\_{2}-L\_{1})}{(t\_{2}-t\_{1})(L\_{2}+L\_{1})}$

where,

* W₁ & W₂ = Initial and final dry weights (g)
* L₁ & L₂ = Initial and final leaf areas (cm²)

t₁ & t₂ = Time intervals (days)

**Statistical Analysis:** The gathered data were statistically analyzed following ANOVA for a factorial randomized block design (FRBD) as outlined by Gomez & Gomez (1984)[14]. The Critical Difference (CD) was computed wherever the F-test was significant at the 5% probability level.

3. results and discussion

**3.1 Physiological Growth attributes**

**3.1.1. Leaf area index**

The data on the mean Leaf Area Index (LAI) of pearl millet recorded at 20 Days After Transplanting (DAT), 45 DAT, and at harvest are presented in (Table 2 and Figure 1). At 20 DAT, there were no significant differences in LAI among the treatments. However, as the crop progressed, variations among the treatments became evident. Among the hydrogel treatments, the application of 5 kg ha-1 recorded a higher LAI of 1.33 at 20 DAT and 2.70 at 45 DAT, closely followed by the 7.5 kg ha-1 application, which recorded 1.31 and 2.63 at 20 and 45 DAT, respectively. The control treatment under hydrogel exhibited a lower LAI values (0.99 during 20 DAT and 45 DAT), indicating the positive impact of hydrogel application on leaf area development. Similarly, among the mulching treatments, polythene mulching showed the highest LAI at 20 DAT and 45 DAT (1.27 and 2.22, respectively), followed by paddy straw mulching (1.19 and 2.13). The control treatment under mulching recorded a lower LAI of 1.10 at 20 DAT and 1.73 at 45 DAT. A significant interaction between hydrogel and mulching was observed, where the combination of 5 kg ha-1 hydrogel with polythene mulching exhibited the maximum LAI of 2.93 at 45 DAT. This suggests that both treatments worked synergistically to improve soil water retention and to reduce water stress, leading to enhanced leaf expansion and canopy coverage. Hydrogels increase soil water-holding capacity, ensuring a steady water supply to plants, while mulching prevents excessive soil moisture loss by reducing evaporation. Enhanced water availability promotes optimal cell turgor, ensuring better leaf development and chlorophyll biosynthesis, ultimately improving photosynthetic activity[15,16].

**3.1.2 Crop growth rate (CGR)**

Crop growth rate (CGR) varied significantly across treatments (Table 2 and Figure 2). Under hydrogel treatments, a higher CGR value of 4.46 g m-2 day-1 was recorded under the 5 kg ha-1 application during the 45 DAT to harvest period, followed by 7.5 kg ha-1 (4.42 g m-2 day-1). Among the mulching treatments, polythene mulching showed a higher CGR value during 45 DAT to harvest period (4.23 g m-2 day-1), followed by paddy straw mulching (4.16 g m-2 day-1). The control treatment under mulching recorded a lower CGR of 3.93 g m-2 day-1 at 45 DAT to harvest. A significant interaction between hydrogel and mulching was observed, as treatments with both 7 kg ha-1 hydrogel and polythene mulching exhibited higher CGR (4.65g m-2 day-1) which was very closely followed by the treatment 5 kg ha-1 hydrogel and polythene mulching (4.57 g m-2 day-1) during 45 DAT to harvest period. This interaction indicates that optimal soil moisture conservation through both methods enhanced root activity, leading to higher nutrient uptake and sustained biomass accumulation. Hydrogels could have prevented moisture stress-induced reduction in cell division and expansion, while mulching could have stabilized the soil temperature, favoured soil microbial activities that may hinder growth. These treatments together ensure better root elongation and proliferation, leading to increased metabolic efficiency and dry matter accumulation[17,18].

**3.1.3 Net Assimilation Rate (NAR)**

Net Assimilation Rate (NAR) showed a significant increase with hydrogel and mulching applications (Table 2 and Figure 3). Among the hydrogel treatments, 7.5 kg ha-1 dosage treatment recorded a higher NAR during the 45 DAT to harvest period (3.88 g m-2 day-1), followed by 5 kg ha-1 dosage treatment (3.72 g m-2 day-1). Among the mulching treatments, there were no significant difference exist among all the treatments and they were all on par with each other. Similarly, among the hydrogel vs mulching interaction there were also no significant interactions existed for NAR. Increased soil moisture through mulching treatments could have ensured higher stomatal conductance, leading to improved CO2 fixation and greater dry matter production. Hydrogels maintained soil hydration levels critical for enzymatic activities related to carbon assimilation, while mulching minimizes photoinhibition by regulating leaf temperature, ensuring continuous photosynthetic activity[19, 20].

**3.2 Yield**

The grain yield of pearl millet was significantly influenced by both hydrogel and mulching treatments. Among the hydrogel treatments, a higher yield was recorded in the 5 kg ha-1 application (24.40 q ha-1), followed by 7.5 kg ha-1 (24.10 q ha-1). The control treatment under hydrogel recorded a lower yield (17.10 q ha-1). Among the mulching treatments, polythene mulching resulted a higher yield (22.4 q ha-1), followed closely by paddy straw mulching (21.8 q ha-1). The control treatment under mulching recorded a lower yield of 20.0 q ha-1.While studying the interaction effects**,** the combination of 5 kg ha-1 hydrogel with polythene mulching resulted a higher grain yield (25.70 q ha-1), demonstrating a strong interaction between hydrogel and polythene mulching. These treatments together could have enhanced the soil water conservation, thereby reducing the plant stress during the critical grain-filling stages. Hydrogels provide a steady water supply, preventing reproductive-stage drought stress that can lead to flower abortion, while mulching minimizes fluctuations in soil temperature, protecting delicate root hairs and improving nutrient availability. The synergistic effect ultimately maximizes grain filling efficiency, resulting in higher productivity[21, 22].

4. Conclusion

The study demonstrated the integration of hydrogel and mulching practices for enhanced pearl millet growth and productivity. The combination of 5 kg ha-1 hydrogel with polythene mulching has resulted in a better physiological eventually leading to a higher grain yield, highlights a strong synergistic effect. Hydrogels improved the soil moisture retention, facilitated a sustained soil moisture availability, reducing the water stress, while mulching minimized the evaporation and efficient weed control, leading to improved physiological efficiency. These findings suggest that hydrogel and mulching application can serve as a sustainable water management strategy, making them invaluable in drought-prone areas. for enhancing pearl millet productivity, especially in drought-prone regions. They help reducing the irrigation needs and enhancing the crop resilience. Future research may explore long-term soil health effects and cost-effectiveness to further optimize these practices for large-scale adoption.

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**Table 2. Impact of combining effect of hydrogel and mulching practices on physiological growth attributes and yield of pearl millet**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatment** | **Leaf Area Index** | **Crop Growth Rate (g m-2 day-1)** | **Net Assimilation Rate (g m-2 day-1)** | **Yield (q ha-1)** |
| **20 DAT** | **45****DAT** | **Harvest** | **20-45 DAT** | **45 DAT-Harvest** | **20-45 DAT** | **45 DAT-Harvest** |
| 1. **Pusa** **hydrogel**
 |
| H1 | No hydrogel | 0.99 | 0.99 | 1.11 | 13.70 | 3.58 | 5.03 | 3.02 | 17.1 |
| H2 | 2.5 kg ha-1 | 1.12 | 1.78 | 1.18 | 13.53 | 3.96 | 5.31 | 3.40 | 20.0 |
| H3 | 5 kg ha-1 | 1.33 | 2.70 | 1.24 | 13.24 | 4.46 | 5.20 | 3.72 | 24.4 |
| H4 | 7.5 kg ha-1 | 1.31 | 2.63 | 1.21 | 13.28 | 4.42 | 4.72 | 3.88 | 24.1 |
|  | S.E (d) ± | 0.13 | 0.02 | 0.01 | 0.01 | 0.01 | 0.09 | 0.19 | 0.02 |
|  | CD (p=0.05) | NS | 0.05 | 0.02 | 0.02 | 0.01 | 0.19 | 0.39 | 0.05 |
| 1. **Mulching**
 |
| M1 | No mulching | 1.10 | 1.73 | 1.16 | 13.55 | 3.93 | 5.06 | 3.41 | 20.0 |
| M2 | Paddy straw mulching | 1.19 | 2.13 | 1.18 | 13.38 | 4.16 | 5.08 | 3.62 | 21.8 |
| M3 | Polythene mulching | 1.27 | 2.22 | 1.22 | 13.38 | 4.23 | 5.06 | 3.49 | 22.4 |
|  | S.E (d) ± | 0.13 | 0.02 | 0.01 | 0.01 | 0.01 | 0.09 | 0.19 | 0.02 |
|  | CD (p=0.05) | NS | 0.05 | 0.02 | 0.02 | 0.01 | NS | NS | 0.05 |
| 1. **Interaction (H x M)**
 |
| **H1M1** | - | 0.72 | 1.07 | 13.75 | 3.45 | 5.01 | - | 16.10 |
| **H1M2** | - | 1.11 | 1.13 | 13.65 | 3.63 | 5.40 | - | 17.5 |
| **H1M3** | - | 1.14 | 1.13 | 13.69 | 3.66 | 4.67 | - | 17.70 |
| **H2M1** | - | 1.52 | 1.17 | 13.58 | 3.83 | 5.62 | - | 19.10 |
| **H2M2** | - | 1.89 | 1.17 | 13.48 | 4.00 | 4.79 | - | 20.30 |
| **H2M3** | - | 1.93 | 1.20 | 13.51 | 4.03 | 5.52 | - | 20.50 |
| **H3M1** | - | 2.38 | 1.20 | 13.44 | 4.23 | 4.66 | - | 22.70 |
| **H3M2** | - | 2.78 | 1.23 | 13.02 | 4.58 | 5.55 | - | 24.80 |
| **H3M3** | - | 2.93 | 1.30 | 13.24 | 4.57 | 5.37 | - | 25.70 |
| **H4M1** | - | 2.29 | 1.20 | 13.41 | 4.20 | 4.94 | - | 22.00 |
| **H4M2** | - | 2.73 | 1.20 | 13.33 | 4.40 | 4.54 | - | 24.60 |
| **H4M3** | - | 2.86 | 1.23 | 13.08 | 4.65 | 4.67 | - | 25.50 |
| S.E. ± | 0.23 | 0.04 | 0.02 | 0.02 | 0.01 | 0.16 | 0.33 | 0.04 |
| CD (p=0.05) | NS | 0.08 | 0.04 | 0.04 | 0.02 | 0.32 | NS | 0.09 |

Fig. 1. Impact of combining effect of hydrogel and mulching practices on leaf area index

Fig. 2. Impact of combining effect of hydrogel and mulching practices on crop growth rate

Fig. 3. Impact of combining effect of hydrogel and mulching practices on net assimilation rate