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Influence of crop residues as mulch on the productivity of pearl millet [*Pennisetum Glaucum* (L.)] under rainfed condition

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Abstract
A field experiment was conducted at the Regional Agricultural Research Station, Vijayapur, during the *kharif* seasons of 2020, 2021, and 2022 on sandy loam soil. The study followed a randomized block design with three replications. The treatments were as follows: T_1 - Control, T_2 - Crop residue (CR) mulch at 5.0 t ha^{-1}, T_3 - Pusa Hydrogel (dry) at 5.0 kg ha^{-1}, T_4 - SPG 1118 (dry) at 5.0 kg ha^{-1}, T_5 - Pusa Hydrogel (slurry) at 5.0 kg ha^{-1}, T_6 - SPG 1118 (slurry) at 5.0 kg ha^{-1}, T_7 - T_3 + CR mulch at 5.0 t ha^{-1}, T_8 - T_4 + CR mulch at 5.0 t ha^{-1}, T_9 - T_5 + CR mulch at 5.0 t ha^{-1}, and T_{10} - T_6 + CR mulch at 5.0 t ha^{-1}.
The combined analysis over three years showed that treatment T_{10} (SPG 1118 slurry at 5 kg ha^{-1} + CR mulch at 5 t ha^{-1}) recorded the highest soil moisture content at both the tillering and flowering stages, with 20.81% and 22.12% at 0-15 cm depth, and 20.99% and 21.45% at 15-30 cm depth, respectively. These values were statistically comparable to T_9 and T_2.
Grain and dry fodder yields were also significantly higher under T_{10} (2242 and 7131 kg ha^{-1}, respectively), followed closely by T_9 (2125 and 7096 kg ha^{-1}) and T_2 (2139 and 6989 kg ha^{-1}). However, the highest net returns (Rs. 25,968 ha^{-1}) and benefit-cost ratio (3.42) were observed in T_2, which also showed significantly higher soil available nitrogen, phosphorus, and potassium levels (232.23, 25.24, and 428.50 kg ha^{-1}, respectively). The lowest net return was recorded in the control (T_1) with Rs. 17,559 ha^{-1}.
Crop residue mulching effectively reduced weed population, improved the microclimate around the root zone, and consequently enhanced pearl millet yield and profitability.

Keywords: Pearl millet, crop residue, mulching, grain yield, nitrogen, phosphorus, potassium

1. Introduction

Pearl millet (*Pennisetum glaucum* L.) holds significant importance for farmers in arid and semi-arid regions due to its remarkable tolerance to moisture limitations and adaptability to shallow soils. Commonly referred to as bajra, cattail, spiked or bulrush millet, it stands out for its nutritional value, making it a crucial crop in these challenging environments. Pearl millet, known for its deep root system, can penetrate soil depths of up to 180 cm. This extensive root penetration helps the plant efficiently utilize soil moisture, allowing it to withstand drought conditions effectively. As a C_4 plant, pearl millet boasts high dry matter production and superior photosynthetic efficiency.

Despite its potential, the realized productivity of pearl millet remains below expectations. The primary reason for poor yield performance is limited moisture availability during the crop's growth period. Since moisture is the most limiting factor in rainfed farming, where rainfall serves as the sole source of water, *in-situ* rainwater conservation in the root zone is the most cost-effective technique for improving moisture availability to plants.

Field crops generate large quantities of residues that are often treated as waste materials. Crop residue production from agriculture is estimated at 140 billion metric tonnes [3]. These residues represent one of the largest sources of soil organic matter in agricultural systems, highlighting the importance of their recovery, recycling, and utilization. However, the burning of crop residues has become a common practice in many countries to quickly clear fields for subsequent cropping.

The use of crop residues as mulch offers a practical and sustainable solution for conserving soil moisture and nutrients under rainfed conditions. Mulch acts as a poor conductor of heat, effectively moderating soil temperature, retaining moisture, and enhancing soil fertility. In this way, mulching serves as an important water conservation technique in rainfed agriculture, optimizing water use and promoting better crop growth and yield [13].

In pearl millet cultivation, stay-green varieties provide valuable fodder for livestock, whereas non-stay-green types often have their residues burned. The burning of crop residues has serious environmental consequences [10], releasing harmful gases and air pollutants that contribute to climate change.

Considering these factors, the present experiment was undertaken to study the growth and productivity of pearl millet as influenced by crop residue cover and to evaluate changes in soil fertility status following the incorporation of crop residues.

2. Materials and Methods

A field experiment was carried out over three consecutive *kharif* seasons (2020, 2021, and 2022) under the All India Coordinated Research Project (AICRP) on Pearl Millet at the Regional Agricultural Research Station (RARS), Vijayapur, which receives an annual rainfall ranging from 550 to 680 mm. The experimental soil was sandy loam in texture, alkaline in reaction (pH 8.35), and low in organic carbon content (0.60%). The available soil nutrients were 212.00 kg ha^{-1} nitrogen, 22.3 kg ha^{-1} phosphorus, and 401.9 kg ha^{-1} potassium.

The experiment was conducted using a randomized block design (RBD) with ten treatments, each replicated three times. The treatments included:

T_1 - Control,
T_2 - Crop residue (CR) mulch at 5.0 t ha^{-1},
T_3 - Pusa Hydrogel (dry) at 5.0 kg ha^{-1},
T_4 - SPG 1118 (dry) at 5.0 kg ha^{-1},
T_5 - Pusa Hydrogel (slurry) at 5.0 kg ha^{-1},
T_6 - SPG 1118 (slurry) at 5.0 kg ha^{-1},
T_7 - T_3 + CR mulch at 5.0 t ha^{-1},
T_8 - T_4 + CR mulch at 5.0 t ha^{-1},
T_9 - T_5 + CR mulch at 5.0 t ha^{-1},
T_{10} - T_6 + CR mulch at 5.0 t ha^{-1}.

Urea and diammonium phosphate (DAP) were used as the sources of nitrogen and phosphorus, respectively. The crop was sown using a seed rate of 4 kg ha^{-1} with a spacing of 45 × 15 cm. The dry powder and slurry forms (dry powder mixed in water) of Pusa Hydrogel and SPG 1118 were applied as per the treatments directly in the seed rows at sowing. Crop residue from the previous year's pearl millet crop was placed between the rows at 15 days after sowing (DAS), following thinning.

From each plot, five plants were randomly selected for recording various growth and yield attributes. Observations were taken on soil moisture content (on a dry weight basis), growth parameters such as plant height (cm) and number of total and effective tillers per plant, and yield components including grain and dry fodder yield (kg ha^{-1}). For determining seed weight per plant, the earheads from sampled plants were threshed separately and grain weight was recorded.

Each net and gross plot was harvested separately to prevent any mixing of produce. The grains from each net plot were cleaned, weighed, and converted to kg ha^{-1} to determine the grain yield. The straw (dry fodder) yield was computed by subtracting the grain yield from the total above-ground biomass and expressed as kg ha^{-1}. Statistical analysis was performed using the least significant difference (LSD) method to determine the significance of treatment effects at the prescribed level of probability [7].

3. Results and Discussion

3.1 Soil moisture content

The pooled data over three years on soil moisture content (Table 1) revealed that treatment T_{10} — application of SPG 1118 in slurry form at 5.0 kg ha^{-1} combined with crop residue (CR) mulch at 5 t ha^{-1} — recorded significantly higher soil moisture content at both the tillering and flowering stages. The observed values were 20.81% and 22.12% at the 0-15 cm depth, and 20.99% and 21.45% at the 15-30 cm depth, respectively. This treatment was statistically on par with T_9 (Pusa Hydrogel slurry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}), which recorded 20.72%, 21.90%, 21.20%, and 21.25%, and with T_2 (CR mulch at 5.0 t ha^{-1}), which recorded 20.40%, 21.58%, 20.80%, and 21.32%, respectively.

The use of organic crop residue mulch reduces soil heat conduction, thereby decreasing the rate of evaporation and ensuring greater moisture retention in the root zone, allowing plants longer access to available water. Upon decomposition, organic mulch enhances the soil's organic matter content, which in turn improves its water-holding capacity [10]. Moreover, organic mulches act as a barrier to heat energy transfer into the soil, thereby lowering soil temperature [12]. The addition of organic matter also promotes soil aggregation, increases porosity by up to 35%, and enhances water infiltration, all of which contribute to better root aeration and improved water availability [8].

Table 1: Effect of moisture conservation through polymers and crop residues on soil moisture content in pearl millet (Pooled mean of three years *Kharif* 2020, 2021 and 2022)

Treatments	At tillering (%)		At flowering (%)	
	0-15 cm depth	15-30 cm depth	0-15 cm depth	15-30 cm depth
T_1	18.14	18.40	19.28	18.90
T_2	20.40	20.80	21.58	21.32
T_3	18.28	18.68	19.99	20.07
T_4	18.74	19.30	19.88	19.76
T_5	18.88	19.33	19.92	20.11
T_6	19.07	19.48	20.30	20.01
T_7	19.97	20.19	21.33	20.99
T_8	20.28	20.54	21.64	20.90
T_9	20.72	21.20	21.90	21.25
T_{10}	20.81	20.99	22.12	21.45
S.Em ±	0.30	0.42	0.35	0.33
C.D.(0.05)	0.89	1.24	1.03	0.99

3.2 Growth attributes

The data on growth attributes indicated that plant height, total tillers, and productive tillers per plant were significantly higher under treatment T_{10} — SPG 1118 in slurry form at 5.0 kg ha^{-1} combined with crop residue mulch at 5 t ha^{-1} — recording 176.3 cm, 4.20, and 3.00, respectively. This treatment was statistically comparable with T_9 (Pusa Hydrogel slurry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}), which recorded 175.2 cm, 4.20, and 2.96, and with T_2 (CR mulch at 5.0 t ha^{-1}), which recorded 174.3 cm, 4.13, and 2.84, respectively. The lowest values were observed in T_1 (Control), with 160.6 cm plant height, 3.64 total tillers, and 2.53 productive tillers.

The application of mulch provides a protective layer over the soil surface, acting as a physical barrier against the erosive effects of wind and water. This not only minimizes soil loss but also preserves soil structure, health, and fertility. Furthermore, the presence of organic mulch encourages the proliferation of beneficial microorganisms in the rhizosphere, enhancing nutrient mineralization, suppressing pathogens, and promoting plant growth. Over time, the decomposition of organic mulches enriches the soil with essential macro- and micronutrients, increases organic matter content, and improves soil structure and aeration — all of which are critical for maintaining long-term soil fertility and productivity [5].

3.3 Yield and economics

Grain and dry fodder yields were significantly higher under treatment T_{10} (SPG 1118 slurry at 5.0 kg ha^{-1} + crop residue mulch at 5 t ha^{-1}), recording 2242 and 7131 kg ha^{-1}, respectively. This treatment was statistically on par with T_9 (Pusa Hydrogel slurry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}), which recorded 2125 and 7096 kg ha^{-1}, and with T_2 (CR mulch at 5.0 t ha^{-1}), which recorded 2139 and 6989 kg ha^{-1}, respectively.

However, the highest net returns (₹25,968 ha^{-1}) and benefit-cost (B:C) ratio (3.42) were observed in T_2, while the lowest net returns were recorded in the control treatment (T_1) with ₹17,559 ha^{-1}.

The use of crop residues as mulch enriches the soil with organic matter upon decomposition, lowers soil temperature, minimizes evaporation and runoff, and fosters a favorable microclimate conducive to plant growth—collectively enhancing yield and economic returns. Adopting conservation agriculture practices such as residue retention, mulching, and zero tillage has been shown to improve soil health, promote vigorous crop growth, increase productivity, and enhance input use efficiency [2, 11]. In temperate regions, the incorporation of crop residues along with farmyard manure (FYM) in arid tropical soils has been found to improve soil water storage, nutrient availability, and crop yield[1]. Overall, the integration of crop residues provides multiple synergistic benefits—boosting crop growth, improving yield attributes, and ultimately contributing to higher grain yields [6].

3.4 Soil nutrient status

The data on post-harvest soil nutrient status of pearl millet revealed that treatment T_2 (crop residue mulch at 5.0 t ha^{-1}) recorded significantly higher available nitrogen, phosphorus, and potassium levels (232.23, 25.24, and 428.50 kg ha^{-1}, respectively). This treatment was statistically comparable with other treatments that included crop residue mulch, namely T_{10} (SPG 1118 slurry at 5.0 kg ha^{-1} + CR mulch at 5 t ha^{-1}) with 229.43, 24.58, and 428.97 kg ha^{-1}; T_9 (Pusa Hydrogel slurry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}) with 230.37, 24.71, and 434.77 kg ha^{-1}; T_8 (SPG 1118 dry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}) with 228.67, 26.36, and 425.10 kg ha^{-1}; and T_7 (Pusa Hydrogel dry at 5.0 kg ha^{-1} + CR mulch at 5.0 t ha^{-1}) with 222.63, 24.85, and 419.83 kg ha^{-1}, respectively.

The continuous decomposition of crop residues over the years enriched the soil with essential macro- and micronutrients, enhanced organic matter content, and improved soil structure and aeration — all of which are crucial for maintaining high soil fertility and sustainable productivity. Mulching significantly contributed to improved crop performance by conserving soil moisture, moderating soil temperature, suppressing weed growth, and promoting long-term soil health[4]. Additionally, the application of crop residues helped create a stable and favorable microenvironment that supported strong root development, enhanced nutrient uptake, and stimulated microbial activity, ultimately leading to greater plant vigor and resilience [9].

Table 2: Effect of moisture conservation technologies on growth, yield and net returns of pearl millet (Pooled mean of three years *Kharif* 2020, 2021 and 2022)

Treatments	Plant height (cm)	No of total tillers plant^{-1}	No of productive tillers plant^{-1}	Grain yield (kg ha^{-1})	Dry fodder yield (kg ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
T_1	160.6	3.64	2.53	1614	5314	17,559	2.79
T_2	174.3	4.13	2.84	2139	6989	25,968	3.42
T_3	167.6	3.80	2.58	1861	6121	16,835	2.15
T_4	169.1	3.78	2.58	1768	6046	15,265	2.05
T_5	169.2	3.87	2.62	1844	6492	16,535	2.13
T_6	169.9	3.91	2.64	1957	6496	18,518	2.26
T_7	171.6	3.98	2.73	2055	6861	19,476	2.26
T_8	172.4	4.04	2.82	2057	6961	19,459	2.26
T_9	175.2	4.20	2.96	2125	7096	20,722	2.34
T_{10}	176.3	4.20	3.00	2242	7131	22,834	2.47
S.Em ±	1.9	0.07	0.05	65.6	171.5	1183.1	0.08
C.D.(0.05)	5.6	0.21	0.16	194.8	509.5	3515.3	0.23

Table 3: Effect of moisture conservation technologies on nutrient status of soil after harvest of pearl millet (After *Kharif* 2022 harvest)

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1	203.03	21.12	393.47
T_2	232.23	25.14	428.50
T_3	206.23	22.60	404.70
T_4	210.30	21.59	396.70
T_5	198.17	22.15	401.23
T_6	208.83	20.70	407.07
T_7	222.63	24.85	419.83
T_8	228.67	26.36	425.10
T_9	230.37	24.71	434.77
T_{10}	229.43	24.58	428.97
S.Em ±	7.52	0.97	9.16
C.D.(0.05)	22.35	2.88	27.21

4. Conclusion

The experimental findings revealed that treatment T_2, i.e., crop residue (CR) mulch at 5.0 t ha^{-1}, produced significantly higher grain and dry fodder yields in pearl millet. The application of polymers along with crop residues (T_{10}) also resulted in increased yields; however, the higher cost of polymers elevated the overall cost of cultivation, thereby reducing net returns.

Crop residue mulching provided multiple agronomic and environmental benefits by enhancing soil health, improving crop productivity, and promoting ecosystem resilience. It effectively conserved soil moisture, moderated temperature fluctuations, suppressed weed growth, and improved soil fertility, thereby mitigating the challenges associated with water scarcity and contributing to the sustainability of rainfed farming systems.

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