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Response of pearl millet (*Pennisetum glaucum*) to crop residue application and potassium management options under rainfed condition

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2021 and 2022 at ICAR-Indian Agricultural Research Institute, New Delhi to study the impact of crop residue mulching and potassium management options on growth and yield attributes of pearl millet [*Pennisetum glaucum* (L.) R. Br]. The experiment was conducted in a split plot design (SPD) with three mains plots, viz. C_0, No residue mulching; C_1, Crop residue mulching @3 t/ha; and C_2, Crop residue mulching @3 t/ha + Pusa decomposer; and five potassium management in sub plot, viz. K_0, No potassium application; K_1, 40 kg K_2O/ha; K_2, 40 kg K_2O/ha + potassium solubilising bacteria (KSB); K_3, 30 kg K_2O/ha + KSB; and K_4, 20 kg K_2O/ha + KSB. Pearl millet variety Pusa Composite 701 was used for the experiment. Significant variation among growth and yield parameters were observed under crop residue as well as potassium management options. Under crop residue mulching these were recorded maximum in treatment C_2 (crop residue mulching @3 t/ha + Pusa decomposer). However, under potassium management options plant height (11.8–13.3%), ear head length (9.5 and 9.8%) and yield (26.7 and 24%) of pearl millet was recorded maximum in treatment K_2 (40 kg K_2O/ha + KSB) during the consecutive year over the control. These finding highlights the synergistic effects of potassium and residue management demonstrating that the presence of KSB enhanced potassium uptake by the plants, resulting in improved outcomes.

Keywords: Crop residue, Pearl millet, Potassium solubilising bacteria, Potassium levels, Rainfed, Seed yield

In India, pearl millet [*Pennisetum glaucum* (L.) R. Br] ranks as the fourth most extensively cultivated food crop following rice, wheat, and maize. During the 2020–21 and 2021–22 agricultural years, it was grown on 7.65 million hectares and 6.70 million hectares respectively, with an average yield of 1420 kg/ha in 2020–21 and 1436 kg/ha in 2021–22. The total production reached 10.86 million tonnes in 2020–21 and 9.62 million tonnes in 2021–22 (Anonymous 2023). Crop residue burning is a common agricultural practice in different parts of the world, including India and it has significant implications for climate change (Kumar *et al.* 2015). This practice involves the deliberate burning of leftover crop residues, such as straw, stalks and husk after the main harvest season to clear fields and prepare them for the next planting season (Sahu *et al.* 2015). This leads not only to the emission of harmful gases and air pollutants into the atmosphere (Gadde *et al.* 2009) but also results in the loss of nutrients (Sahu *et al.* 2015). By adopting conservation agriculture (CA) practices, retaining/mulching crop residues, zero tillage practice, and crop rotation, demonstrated to enrich soil health, resulting robust crop growth, increasing agricultural productivity and optimizing input use efficiency (Meena *et al.* 2016).

Potassium (K), the third most vital macronutrient for crop plants, is crucial for their growth, yield, and the activation of various metabolic processes (Wakeel *et al.* 2016). In India, the import of potash fertilizer saw a slight increase of 30%, rising from 4.04 million tonnes in the previous year to 5.25 million tonnes in 2020–21 (Indian Minerals Book 2021). To address this issue, it is imperative to explore alternative sources of K that can fulfil the nutritional requirements of plants and maintain soil K levels to sustain crop production (Sustr *et al.* 2019). Traditional inorganic K fertilizers tend to become bound with other minerals in the soil, making only a minimal 1–2% of the applied K available for crop uptake (Sparks 1987).

KSB have the capability to release K from minerals by secreting organic acids (Meena *et al.* 2015). However, the effectiveness of KSB is largely influenced by their successful establishment in the soil, which can vary based on factors such as the specific bacterial strains used, crop management practices, and the types of crops grown. Considering these

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factors, a study was planned to examine the effects of crop residue mulching and potassium management on the growth and yield attributes of pearl millet.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) seasons of 2021 and 2022 at ICAR-Indian Agricultural Research Institute, New Delhi (28.35°N latitude, 77.12°E longitude, and an altitude of 228.6 m amsl). The mean rainfall of 1413.7 and 819.8 mm was received during 2021 and 2022 and the mean evaporation 83.33 and 79.87 mm, respectively. The mean maximum temperature varied from 34.61 and 34.66°C and mean minimum temperature from 25.52°C and 24.82°C for *kharif* pearl millet during 2021 and 2022. The experimental soil was characterised by *p*H, 7.48; EC, 0.20 dS/m; soil organic carbon, 0.47%; N, 146 kg/ha; P, 17.6 kg/ha; and K, 228 kg/ha and bulk density, 1.51 g/cc (Datta *et al.* 2017). The experiment was laid out in a split plot design (SPD) with 15 treatment combinations, replicated thrice. The main plots included three treatments, viz. C_0, No crop residue mulching; C_1, Crop residue mulching at 3 t/ha; and C_2, Crop residue mulching at 3 t/ha combined with Pusa decomposer. The sub-plots consisted five different potassium levels, viz. K_0, Control; K_1 40 kg K_2O/ha; K_2, 40 kg K_2O/ha with KSB; K_3, 30 kg K_2O/ha with KSB; and K_4, 20 kg K_2O/ha with KSB. Pearl millet variety Pusa Composite 701 was sown on July 17th, 2021, and July 14th, 2022, using a turbo-seeder at a seed rate of 4.0 kg/ha, with a spacing of 45 cm × 15 cm. The recommended doses of fertilizer, as described earlier, were applied according to the treatment specifications. The full doses of phosphorus (P) and potassium (K), along with half dose of the nitrogen (N), were administered at sowing. The remaining nitrogen fertilizer was applied in two equal splits; 25% at the knee-high stage and 25% at the ear-head initiation stage. The nutrient sources were urea for nitrogen, diammonium phosphate for phosphorus, and muriate of potash for potassium. Pearl millet seeds were treated with potassium solubilizing bacteria (KSB) at a rate of 50.0 ml/acre according to the treatment plan. Sun-dried, chopped wheat residue was used as mulch, retained on the soil surface, and a consortium (Pusa decomposer) was sprayed on the mulch after sowing. To maintain a weed-free environment, pendimethalin @1 kg a.i./ha and atrazine @0.75 kg a.i./ha were applied as pre-emergence herbicides one day after sowing.

Growth and yield attributes: Standard methods were followed as per the recommendation of Rana *et al.* (2014) for growth and corresponding attributes. The growth and yield attributes, including plant height, the number of effective tillers per meter of row length, and the leaf area index, were assessed at 30 days, 60 days and at the harvest stage of the crop. Measurements of row length were taken using a meter scale, and tillers within a 1m row length were counted. After harvesting of the crop, five tagged earheads selected per plot in each replication were utilized for measuring earheads length (cm) and earheads girth (cm). Test weight (g) was taken and reported at 12% of seed moisture content level.

Statistical analysis: Data analysis involved two-way analysis of variance using the R studio for split plot design to compare the data between the treatments and with control. A significance level of P=0.05 was employed to evaluate statistical significance.

RESULTS AND DISCUSSION

Growth parameters: Crop residue mulching and different K doses with KSB significantly affected the growth attributes in both the years at 60 days after sowing (DAS) and at harvest stage of pearl millet. Plant height significantly increased by 8.3% and 9.2% respectively, over control (C_0) in the year 2022 (Table 1). However, no significant differences were recorded in the plant height of pearl millet at harvest during 2021. Number of tillers/m row length increased significantly with C_2 at harvest of crop and was 17.2% and 25.4% higher as compared to C_0 (control) in the year of 2021 and 2022, respectively. Bana *et al.* (2016) also reported maximum number of tillers/m row length with organic mulching and nutrient management in three years of study under pearl millet + cluster bean intercropping system. Leaf area index (LAI) of crop at initial phase of crop growth (30 DAS) was not significantly with application of crop residue and different potassium management options, irrespective of experimental years. However, at 60 DAS of crop growth stage, LAI varied significantly affected with application of crop residue and potassium management in both the years. Application of crop residue + Pusa decomposer (C_2) recorded maximum LAI (4.50 and 4.62) but was at par with only crop residues mulching @3 t/ha and it was 12% and 13.2% higher over without crop residues mulched plots in the year of 2021 and 2022, respectively (Table 1). The minimum LAI (4.02 and 4.08) was observed under no residue mulching (C_0) in 2021 and 2022, respectively. Mulching along with/without decomposer helped to conserve soil moisture by reducing evaporation and improving soil fertility by adding organic matter, which slowly releases essential nutrients and uptake by crops resulted in enhanced crop growth and development. This study results were in line with Patel *et al.* (2018), who advocated wheat straw incorporation in soil and the application of decomposer fungal consortia (@1 litre/t) along with 25 kg N/ha improved different growth factors of pearl millet. Crop residue mulching conserves soil moisture by decreasing evaporation and minimizing water runoff (Prem *et al.* 2020). Moreover, using residue as a moisture management technique enhances nutrient availability through the decomposition of organic matter, thereby creating an optimal environment for plant growth and development (Choudhary *et al.* 2014).

Among the potassium management option, treatment K_2 (40 kg K_2O + KSB) resulted in significantly greater plant height (254 cm and 256 cm) at harvest, representing increase of 11.8% and 13.3% compared to the control treatment in 2021 and 2022, respectively. Treatment K_3 (30 kg K_2O +

Table 1 Effect of crop residue mulching, potassium management and biofertilizer on growth parameters of pearl millet during 2021 and 2022

Treatment	Plant height (cm)						Number of tillers/m row length						Leaf area index			
	30 DAS		60 DAS		Harvest stage		30 DAS		60 DAS		Harvest stage		30 DAS		60 DAS	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Crop residue management																
C_0	41.8	42.4	214	213	237	229	12.1	13.6	22.8	21.6	23.2	22.4	1.40	1.34	4.02	4.08
C_1	42.1	43.6	224	229	246	248	14.3	14.3	26.1	26.4	26.7	27.9	1.43	1.49	4.43	4.56
C_2	42.4	45.0	227	230	249	250	14.6	14.4	26.4	26.6	27.2	28.1	1.44	1.48	4.50	4.62
SEm±	0.6	0.6	2.9	3.0	3.3	3.2	0.59	0.4	0.7	0.8	0.7	0.5	0.02	0.04	0.09	0.08
LSD (P=0.05)	NS	NS	NS	11.6	NS	12.6	NS	NS	2.9	3.0	2.8	2.0	NS	NS	0.34	0.33
Potassium management option																
K_0	41.6	42.5	207	211	227	226	12.9	13.6	22.3	21.4	22.4	22.9	1.37	1.33	3.89	3.94
K_1	41.8	43.6	222	224	245	242	13.6	14.2	25.1	24.7	25.7	26.2	1.44	1.39	4.40	4.53
K_2	43.1	45.2	232	235	254	256	14.8	14.5	27.3	27.2	28.1	28.2	1.47	1.52	4.55	4.66
K_3	42.6	44.5	229	231	250	250	13.8	14.2	26.2	26.6	27.2	27.8	1.46	1.53	4.49	4.58
K_4	41.6	42.6	217	220	244	240	13.2	14.1	24.6	24.5	25.0	25.3	1.40	1.42	4.26	4.40
SEm±	0.8	0.9	3.9	4.7	3.5	3.6	0.58	0.6	0.6	0.5	0.6	0.6	0.03	0.06	0.11	0.08
LSD (P=0.05)	NS	NS	11.4	13.6	10.1	10.5	NS	NS	1.7	1.5	1.7	1.9	NS	NS	0.34	0.25

NS, Non-significant; DAS, Days after sowing. Treatment details are given under Materials and Methods.

KSB) also showed improved performance relative to control and was statistically comparable to K_2 at 60 DAS and harvest of crop with respect to plant height of pearl millet in both the years. Treatment K_2 recorded significantly higher number of tillers/m row length (28.1 and 28.2) at harvest of millet in year 2021 and 2022, which was increased by 25.4% and 23.0%, respectively over control. The 30 kg K_2O + KSB (K_3) was found statistically at par with 40 kg K_2O + KSB (K_2) in both experimental years and minimum number of tillers/m row length (22.4 and 22.9) were recorded at harvest stage of pearl millet in control plots, during the year 2021 and 2022, respectively. In 2021, the control plots exhibited the lowest LAI, while other treatments displayed similar LAI values at 60 DAS. In 2022, the highest LAI was observed in the treatment with 40 kg K_2O combined with KSB (K_2), showing a significant increase of 18.3% and 6.0% compared to treatments without potassium application (K_0) and with 20 kg K_2O + KSB (K_4), respectively. This treatment was statistically comparable to 30 kg K_2O + KSB (K_3) and 40 kg K_2O alone (K_1). Potassium is a crucial nutrient for plant growth and development as it plays a role in photosynthesis, converting light energy into chemical energy (sugars), and enhancing the uptake of other essential nutrients (Rawat *et al.* 2016). These findings align with the study by Sakarvadia *et al.* (2012), which suggested that higher potassium doses increase the plant height of millets. Many potassium compounds in the soil are insoluble and not readily available for plant uptake; however, potassium-solubilizing bacteria can produce organic acids and enzymes, such as citric acid, gluconic acid, and oxalic acid, to facilitate potassium availability (Li *et al.* 2020). These organic acids dissolved the insoluble potassium compounds, converted them into soluble forms like potassium ions which is crucial for maintaining cell turgidity. Turgid cells support the structure of leaves, helping them remain open and expand, resulting in a larger leaf area (Zorb *et al.* 2014). Our study was also in line with Reddy *et al.* (2021) that reported application of 50 kg K_2O/ha had significantly higher growth parameters than other treatments in pearl millet.

Yield attributes and yield: Earhead length, earhead girth, weight of 1000-grains and grain yield of pearl millet varied significantly with crop residue management options (Table 2). The crop residue mulching @3 t/ha along with Pusa decomposer significantly increased earheads length with bold grains, greater earhead girth and test weight in both the years. Maximum length of earhead was recorded in crop residue mulching @3 t/ha + Pusa decomposer (C_2) followed by crop residue mulching @3 t/ha and (C_1) and no residue mulching (C_0) in the year 2022. Earhead girth of pearl millet, was recorded statistically similar with 3 t/ha + Pusa decomposer (C_2) and crop residue mulching @3 t/ha (C_1) and it was recorded 5.7% and 4.0% higher compared to no residue mulching (C_0) in first year, but during second year ear girth was recorded significantly higher with 3 t/ha + Pusa decomposer (C_2), which was at par with 3 t/ha (C_1) and it was 6.0% higher as compared to treatment C_0 (no residue mulching). Further the test weight was registered

Table 2 Effect of crop residue mulching, potassium management and biofertilizer on yield attributes and yield of pearl millet during 2021 and 2022

Treatment	Ear head length (cm)		Ear head girth (cm)		Test weight (g)		Grain yield (t/ha)	
	2021	2022	2021	2021	2021	2022	2021	2022
Crop residue management								
C_0	28.8	29.0	8.06	8.14	8.08	8.13	2.19	2.10
C_1	30.6	30.8	8.36	8.46	8.53	8.59	2.49	2.43
C_2	30.8	31.1	8.52	8.63	8.72	8.79	2.54	2.47
SEm±	0.69	0.37	0.07	0.09	0.09	0.10	0.05	0.08
LSD (*P*=0.05)	NS	1.46	0.29	0.35	0.34	0.40	0.19	0.30
Potassium management option								
K_0	28.5	28.7	8.07	8.18	7.96	8.03	2.06	2.03
K_1	30.3	30.5	8.38	8.46	8.53	8.57	2.44	2.36
K_2	31.2	31.5	8.47	8.57	8.73	8.79	2.61	2.52
K_3	30.4	30.7	8.43	8.52	8.61	8.67	2.51	2.42
K_4	29.9	30.1	8.21	8.33	8.39	8.46	2.4	2.32
SEm±	0.43	0.53	0.10	0.09	0.11	0.10	0.04	0.04
LSD (*P*=0.05)	1.26	1.54	0.28	0.27	0.32	0.28	0.12	0.11

NS, Non-significant. Treatment details are given under Materials and Methods.

statistically similar with application of C_2 and C_1 during both the years and it was recorded 8.0% higher compared to C_0 under crop residue management practices. Residue mulching is closely linked to the production of organic acids by bacteria, including tartaric acids, oxalic, citric, malic and succinic acids. These acids contribute to the weakening of chemical bonds in minerals, thereby promoting mineral dissolution (Rawat *et al.* 2016). Among the potassium management options, characteristics of pearl millet yield-attributes were also recorded significantly different across the treatments (Table 2). Earhead length was significantly increased with application of K_2 (40 kg K_2O/ha + KSB) which was on par with K_3 (30 kg K_2O/ha + KSB) and K_1 (40 kg K_2O/ha) in first year while during second year it was recorded statistically similar with treatment K_2 (40 kg K_2O/ha + KSB), K_3 (30 kg K_2O/ha + KSB) and K_1 (40 kg K_2O/ha), which was statistically on par with K_4, but earhead girth of pearl millet was found statistically similar with treatments K_2, K_3 and K_1 and about 5.0%, 4.5% and 3.8% higher as compared to K_0, during both study years. Test weight was significantly higher with treatment K_2 but it was at par among K_3 and K_1 treatments and was increased about 9.5% higher as compared to control during both the experimental years. Higher test weight observed in treatment K_4 over the control plots in both the years. Potassium helps in transportation of nutrients and water within the plant and adequate potassium levels can improve the overall nutrient uptake efficiency of crops, which contributes to increased ear head size as well as test weight too (Pettigrew 2008). Significant variations in grain yield were observed across different crop residue management practices and treatment C_2 recorded significant improvement in yield over no residue application (C_0). Furthermore, C_1 (crop residue mulching @3 t/ha) exhibited statistically similar yields in both experimental years. The incorporation of crop residue offers diverse benefits, encompassing moisture retention, nutrient cycling, support for microbial activity, efficient metabolite partitioning and improved photosynthate accumulation and translocation. These combined factors contribute synergistically to enhanced crop growth, improved yield attributes and ultimately lead to an augmented grain yield, as highlighted by Choudhary *et al.* (2016). Manu *et al.* (2024) found that incorporating paddy straw combined with the application of Pusa decomposer and urea at a rate of 10 kg/ha resulted in significantly higher grain and straw yields of wheat compared to other treatments. In the context of potassium management practices, treatment K_2 (40 kg K_2O/ha + KSB) demonstrated a significantly higher grain yield, recording a 26.7% and 24% increase during 2021 and 2022, respectively as compared to control. Remarkably, this performance paralleled that of treatments K_3 (30 kg K_2O + KSB) and K_1 (40 kg K_2O/ha) across both years. Potassium is vital for several key functions in plants, including enzyme activation, photosynthesis, and the transport of water and nutrients. Ensuring sufficient potassium levels is essential for overall plant health and can lead to higher crop yields. However, the interaction between crop residue mulching and potassium management practices did not show a significant effect on plant growth, yield attributes, or overall yield. These findings align closely with the conclusions drawn by Asodariya *et al.* (2021). Combination of residue mulching, potassium application along with biofertilizer (KSB), created optimum environment for nutrient supplying capacity of soil as per demand of crop by preventing moisture loss. This creates a more favourable environment for crops, allowing it to maintain optimal moisture levels and it can also act as a natural weed barrier, reducing competition for nutrients and water (Kaur *et al.* 2018). Asodariya *et al.* (2021) also reported that the application of 80 kg K_2O/ha recorded significantly highest effective tillers per plant with as compared to control.

The use of crop residue mulching, both with and without the addition of a decomposer, significantly enhanced growth and improved yield attributes compared to plots lacking mulching. In potassium management practices, the application of potassium at a rate of 40 kg K_2O/ha, combined with the use of potassium solubilizing bacteria @50 ml/acre for seed treatment, demonstrated notable improvements in growth parameters, yield attributes, overall yield and grain yield in pearl millet.

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