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Short Communication

ORIGINAL ARTICLE

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Comparative Effects of Crop Residue Mulches on Weed Dynamics, Soil Moisture, and Yields of Chickpea (*Cicer arietinum L.*) Under Rainfed Conditions

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ABSTRACT

In rainfed chickpea cultivation, soil moisture stress and severe weed infestation are major constraints limiting productivity, while open-field burning of crop residues poses serious environmental concerns. With this background, an experiment was conducted during the winter or *Rabi* season of 2022-23 at Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, to evaluate the effects of different crop residue mulches on weed dynamics, soil moisture conservation, growth, and yield of chickpea. The experiment was laid out in a randomized block design (RBD) with seven treatments and three replications. The treatments included: without mulch, dust mulch, paddy straw mulch @ 5 t ha^{-1}, maize stover mulch @ 5 t ha^{-1}, *Leucaena* twigs mulch @ 5 t ha^{-1}, paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}, maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}. Results revealed that the application of paddy straw mulch at 5 t ha^{-1} was the best treatment for reducing weed density and biomass at 60 and 90 DAS of chickpea. Although dust mulching recorded lower weed density and biomass at 30 DAS, it was ineffective during the subsequent crop growth period due to rapid flushes and proliferating weed germination. The maximum mid-season surface soil moisture (16.7%) was recorded under paddy straw mulch @ 5 t ha^{-1} at 60 DAS, and it was found at par with paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} while the minimum was observed under no mulch treatment. Moreover, paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} excelled over all other treatments in terms of growth, yield parameters, and yield. Hence, application of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} may be recommended for higher growth and yield of chickpea under rainfed conditions similar to the experimental site.

1 | INTRODUCTION

Crop residue burning in India, especially in the Indo-Gangetic Plains, is a major environmental and agricultural issue, with nearly 100 million tonnes burned annually (Lan *et al*., 2022), including 22.38 MT in Uttar Pradesh (Bhuvaneshwari et al., 2019). Despite strict monitoring, incidents increased by over 18% in 2025 compared to 2024 (Times of India, 2025). Burning facilitates quick field clearing but releases greenhouse gases and particulate matter, contributing to pollution, health risks, and climate change (IPCC, 2019). This underscores the urgent need for sustainable residue management. Alternatives like in-situ incorporation, mulching, composting, biochar, and bioenergy are promoted. Among these, surface mulching improves soil microclimate, conserves moisture, suppresses weeds, and boosts soil organic carbon (Meshram *et al.*, 2022). It's especially useful in rainfed systems where moisture is limited and evaporation causes water loss, helping to improve resource efficiency and crop stability in water-scarce environments (Madhu and Jinger 2025 a, b).

Chickpea (*Cicer arietinum* L.) is a major pulse crop in India, accounting for 32.3% of the global pulse area and 40.9% of production. It is valued for its high protein content (18–22%) and nutritional importance (Jukanti *et al*., 2012). However, productivity in rainfed regions remains low due to limited soil moisture during critical growth stages and severe weed competition, especially early in crop establishment (Patel *et al.,* 2024). Preserving residual soil moisture from the previous rainy season is therefore vital for successful rainfed chickpea cultivation (Rajak & Prasad, 2017). Mulching has been shown to reduce evaporation

(Ramos *et al.*, 2024), improve soil moisture retention (Kumari *et al.*, 2024), and enhance soil health and productivity (Singh & Dhillon, 2022). Although many studies highlight the benefits of individual mulch materials (Rajak & Prasad, 2017; Rao *et al.*, 2021), there is limited information on the comparative and combined effects of different residue mulches in rainfed chickpea systems. Specifically, the potential benefits of combining multiple residue types have not been thoroughly explored.

In this context, using crop residues as surface mulches offers an environmentally friendly alternative to burning residues. It also helps in managing soil moisture stress and weeds. This study was conducted to evaluate how different crop residue mulch treatments affect soil moisture retention, weed behavior, plant growth, and chickpea yield in rainfed conditions. The hypothesis was that optimal residue combinations could increase soil moisture, reduce weed growth, and boost chickpea productivity.

2 | MATERIALS AND METHODS

2.1 | Experimental Site and Weather Conditions

The experiment was conducted during the winter or *Rabi* season of 2022-23 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh. Varanasi is located in a semi-arid to sub-humid climate belt. The decadal (2012–2023) mean climatic parameters were 31.07 °C for maximum temperature, 19.39 °C for minimum temperature, and 6.48 h day^{-1} for sunshine duration (Fig. 1). Analysis of monthly climatic data (2012–2023) revealed that the mean annual rainfall and PET were 946.6 mm and 1407.6 mm, respectively. The rainy season (June–September) received an average rainfall of 803.7 mm, resulting in a moisture surplus of 335.7 mm, whereas the post-rainy season (October–February) received only 87.8 mm, resulting in a moisture deficit of 219.4 mm. This place typically experiences semi-arid to sub-humid climates, with high and low precipitation, moderate humidity, and seasonal temperature fluctuations. The sandy clay loam soil in the experimental field exhibited low levels of nitrogen (200 kg ha^{-1}), moderate levels of soil organic carbon (0.47%), phosphorus (19.75 kg ha^{-1}), and potassium (140.56 kg ha^{-1}). Both pH (7.44) and electrical conductivity (0.26 dS m^{-1}) of the soil were within the typical range.

2.2 | Experimental Design and Treatments

The experiment was laid out in a randomized block design (RBD) with three replications. The study included seven treatments, viz. without mulch (T_1), dust mulch (T_2), paddy straw mulch @ 5 t ha^{-1} (T_3), maize stover mulch @ 5 t ha^{-1} (T_4), *Leucaena* twigs mulch @ 5 t ha^{-1} (T_5), paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} (T_6), maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} (T_7). Paddy straw, maize stover, and *Leucaena* twigs mulch were applied immediately after sowing of the chickpea. Paddy straw and maize stover from the preceding crops grown in the experiment were utilized, as they were not required for livestock feeding. Additionally, *Leucaena* twigs were collected from boundary plantations at Banaras Hindu University, Varanasi, Uttar Pradesh. The gross and net plot sizes were: 5 m × 4 m and 4.0 m × 3.1 m, respectively.

HIGHLIGHTS

- Paddy straw mulch @ 5 t ha^{-1} most effectively suppressed weeds, recording the lowest weed density and biomass.
- Integrated mulching with paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} significantly enhanced chickpea growth and productivity.
- Residue-based mulching improved soil moisture conservation mid-season, with paddy straw mulch at 5 t ha^{-1} showing the highest soil moisture (16.7%).

2.3 | Crop Management Practices

After the final field preparation, the seeds of the Chickpea variety "RVG-202" were sown at the rate of 80 kg ha^{-1} at a uniform distance of 30 cm between rows and 10 cm distance between plants by seed drill on 15th October 2022. The field was fertilized with recommended doses of N: P_2O_5: K_2O (20: 40: 20 kg ha^{-1}), applied as Di Ammonium Phosphate and Muriate of Potash, respectively. All the doses of nitrogen, phosphorus, and potassium were applied as basal at the time of sowing. Dust mulch (5-8 cm) was applied with a dryland weeder, and weeds were removed once at 25 DAS at a depth of 3-4 cm. This created a finely textured layer of soil. Paddy straw, maize stover, and *Leucaena* twigs were used as mulches to cover the soil between chickpea rows @ 5 t ha^{-1} on a dry biomass basis. The mulch thickness was 4-5 cm. This practice was done immediately after germination, i.e., 10 days after sowing (DAS). The combination of mulches (paddy + *Leucaena*) and maize + *Leucaena* was applied @ 2.5 t ha^{-1} each. The crop was harvested on 20th February 2023 when the plants turned yellow-brown, and the pods became dry and hard. The crop was cut close to the ground with a sickle and sun-dried for five days. After drying, the seeds were separated using a mechanical thresher and cleaned before storage. No incidence of insect pests or diseases was observed during the experimental period. Apart from the prescribed treatments, no additional weed management practices were followed.

2.4 | Data Recording

In each plot, 5 plants were tagged for observations. Weed populations (grasses, broad-leaved weeds, and sedges) were counted in 0.25 m² quadrats, transformed using $\sqrt{x + 0.5}$ to reduce variability. Weed biomass was measured at 30, 60, and 90 DAS from two quadrates per plot, sun-dried, then oven-dried at 70 ± 2 °C for 48 hours, expressed as total weed density and biomass, and transformed similarly. Root nodule numbers and branches per plant were recorded at 50% flowering (60 DAS). Yield attributes (pods, seeds per plant, seed index) were recorded at harvest. Seed and stover yields were extrapolated to kg ha^{-1} from net plot data. Soil moisture at 60 DAS was measured once using the gravimetric method at the 0–15 cm depth, following Reynolds (1970), with sampling via auger and oven drying at 105 °C for 24 hours.

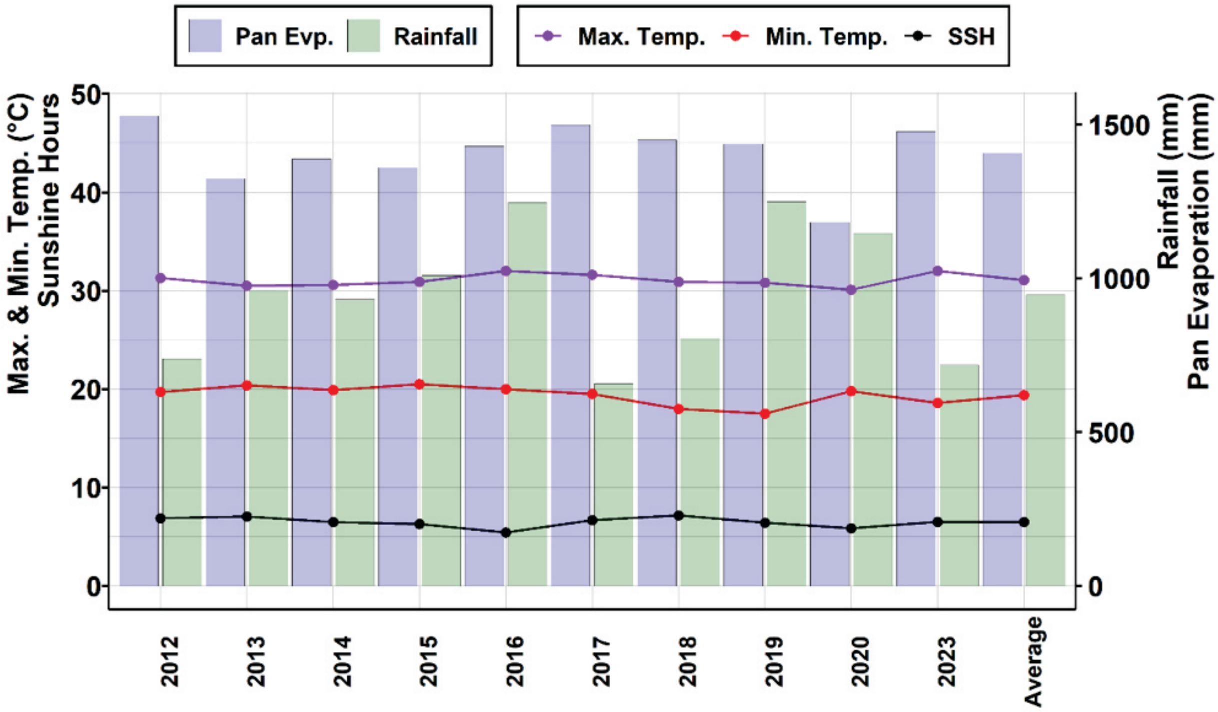

FIGURE 1 Annual variation in rainfall, PET, temperature, and sunshine hours (SSH) from 2012-2023

2.5 | Statistical Analysis

Statistical analysis was carried out to assess the significance of differences between treatment means and to draw valid conclusions. Data from various observed parameters were analyzed using an appropriate Analysis of Variance (ANOVA) technique. The treatment effects were tested for significance using the 'F' test. Mean values were calculated following the methods described by Gomez and Gomez (1984). Additionally, mean comparisons were performed using Tukey's Honestly Significant Difference (HSD) test at a 5% probability level.

3 | RESULTS AND DISCUSSION

3.1 | Effect On The Total Weed Density And Biomass

Mulching treatments exerted a pronounced influence on weed density and weed dry biomass in chickpea at different crop growth stages. Across all observations, mulched plots significantly reduced weed infestation compared with the plot without mulch, which consistently recorded the highest weed density and dry matter accumulation at 30, 60, and 90 DAS (Table 1). Among the treatments, paddy straw mulch @ 5 t ha^{-1} proved most effective, observed the lowest weed density and weed dry biomass at both 60 and 90 DAS, indicating its sustained weed-suppressive potential throughout the crop growth period. Treatments like maize stover mulch @ 5 t ha^{-1}, paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}, and maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} also demonstrated moderate effectiveness in suppressing weed growth, though their performance remained inferior to paddy straw mulching.

At 30 DAS, dust mulch recorded the lowest weed density and weed dry biomass. This initial reduction in weed infestation may be attributed to repeated soil disturbance by the dryland weeder, which physically uprooted or buried newly emerged weeds, thereby disrupting early weed establishment (Verma *et al.,* 2017). However, this suppressive effect was transient. At later growth stages (60 and 90 DAS), weed density and dry biomass increased under dust mulching due to soil inversion and loosening, which enhanced light penetration and created favorable conditions for weed seed germination and subsequent growth. In contrast, paddy straw mulch @ 5 t ha^{-1} consistently maintained significantly lower weed density and dry biomass at 60 and 90 DAS (Table 1). The superior weed suppression under paddy straw mulch may be attributed to its mat-like physical barrier, which restricted light transmission to the soil surface, thereby inhibiting germination of light-sensitive weed seeds. Additionally, the physical persistence of paddy straw ensured prolonged soil cover, reduced soil temperature fluctuations, and limited space for weed emergence throughout the crop period. Sahu *et al.* (2022) reported that application of paddy straw mulch at 5 t ha^{-1} significantly reduced the weed density and weed biomass in chickpea, indicating the effectiveness of organic residue mulching in suppressing weeds through physical obstruction, allelopathic effects, and modification of the soil microenvironment.

3.2 | Effect On the Growth Attaining Characters

The growth attributes of chickpea were significantly influenced by different mulch treatments throughout the crop growth period (Table 2). Among all treatments, the combined application of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} consistently resulted in the highest plant height at all growth stages. Plant height under this treatment reached 26.3 cm, 36.0 cm, and 59.0 cm at 30, 60, and 90 DAS, respectively (Table 2), indicating a sustained positive effect on vegetative growth. This superior performance may be attributed to improved mid-season surface soil moisture conservation and moderated soil temperature under residue mulching, which created a favourable microenvironment for continuous crop growth (Archana *et al.,* 2021).

The number of branches per plant, a critical determinant of yield potential in chickpea, was also significantly affected by mulch treatments. Application of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} recorded the highest number of branches per plant (17.0) compared to other treatments (Table 2). The enhanced branching under residue mulching may be attributed to reduced evaporative losses, improved soil physical conditions, and increased availability of mid-season surface soil moisture and nutrients. Furthermore, effective weed suppression under this treatment reduced crop-weed competition, thereby facilitating improved nutrient uptake and assimilate partitioning, ultimately supporting robust plant architecture. Kumar and Angadi (2016), observed improved plant height and leaf area of chickpea with mulching of maize stalk (4 t ha^{-1}) at Dhardwad region of Karnataka.

Mulching-induced improvements in soil hydrothermal conditions may have contributed to better root development and overall plant growth. Although soil temperature, root architecture, and soil physical properties were not directly measured in the present study, mulching may have enhanced surface soil moisture at 60 DAS, thereby indirectly supporting improved root growth and resource acquisition. The combined effects of improved moisture availability and a moderated soil environment under mulched treatments may have facilitated more efficient water and nutrient uptake. Similar positive associations between organic mulching and improved chickpea growth have been reported by Angmo *et al.* (2018).

The number of root nodules per plant was significantly higher under mulched treatments, with paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} observed the maximum number of nodules (19.4 $plant^{-1}$), followed by paddy straw mulch @ 5 t ha^{-1} with 18.2 nodules $plant^{-1}$. The enhanced nodulation observed under these treatments may be associated with reduced weed infestation, which could have minimized competition for soil nutrients and moisture, thereby creating more favourable conditions for Rhizobium activity. Additionally, although microbial activity and nitrogen dynamics were not directly measured in the present study, crop residue decomposition may have influenced rhizosphere microbial processes, including temporary nitrogen immobilization. Such conditions could potentially stimulate biological nitrogen fixation and nodulation in chickpea, as suggested in earlier studies. Similar explanations have been reported by Sahu *et al.* (2022).

In contrast, the lowest number of root nodules (7.50 $plant^{-1}$) was recorded in the without-mulch plot. This reduction may be associated with higher weed density and greater weed biomass under no mulching, which could have increased competition for soil moisture and nutrients, thereby adversely influencing crop growth and nodulation. Although soil temperature and microbial activity were not directly measured in the present study, the absence of mulch may have resulted in less favourable surface soil moisture conditions at 60 DAS, potentially affecting Rhizobium activity and root development. Similar trends of reduced nodulation under weedy and moisture-limited conditions have been reported by Rao *et al*. (2021).

3.3 | Effect On the Yield Attributing Characters

Mulching treatments significantly influenced yield attributes and chickpea productivity. The combined application of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} recorded the highest number of pods $plant^{-1}$ (60.6) and grains pod^{-1} (1.70), whereas the plot without mulch consistently showed significantly lower values for these yield components (Table 3). The improvement in reproductive parameters under this treatment indicates enhanced assimilate availability and effective partitioning towards sink development under favorable mid-season surface soil moisture and thermal regimes created by residue mulching. Test weight was statistically unaffected by mulching treatments, suggesting that seed size is primarily governed by genetic factors and less responsive to soil surface management practices under the prevailing agro-climatic conditions. Similar observations have been reported in chickpea, where mulching improved yield mainly through increased pod number $plant^{-1}$ and seed number pod^{-1} under rainfed agroecosystems of the semi-arid tropics of India (Sahu *et a*l., 2023).

The superiority of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} was further reflected in seed yield (1749 kg ha^{-1}), stover yield (2606 kg ha^{-1}), and biological yield (4355 kg ha^{-1}), all of which were significantly higher than those obtained under the plot without mulch. The enhanced yields under combined mulching may be associated with higher surface soil moisture content observed at 60 DAS and effective weed suppression, which together could have promoted better crop growth and more efficient utilization of available resources.

Although soil temperature and nutrient dynamics were not directly measured in the present study, the inclusion of *Leucaena* twigs may have improved nutrient availability through their nutrient-rich biomass. Although the harvest index was highest under this treatment (40.2%), differences among treatments were statistically non-significant, indicating that mulching primarily enhanced total biomass production rather than altering biomass partitioning patterns. These findings suggest that integrated organic mulching improves chickpea productivity by increasing both vegetative and reproductive growth without adversely affecting harvest efficiency. These results are in close agreement with recent studies reporting increased chickpea yield under integrated residue-based mulching systems in rainfed environments (Parmar *et al.*, 2023).

TABLE 1 Effect of different mulches on total weed density (no. m^{-2}) and total dry biomass in chickpea (g m^{-2})

	Density of total weeds (no. m^{-2})			Dry biomass of total weeds (g m^{-2})		
Treatment	30 DAS*	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Without mulch	13.36 (178)^{a}	16.26 (264)^{a}	20.65 (426)^{a}	8.86 (78.06)^{a}	11.41 (129.7)^{a}	14.76 (217.5)^{a}
Dust mulch	4.30 (18)^{f}	14.02 (196)^{b}	19.51 (380)^{ab}	2.50 (5.74)^{f}	9.33 (86.9)^{b}	11.75 (137.5)^{b}
Paddy straw mulch @ 5 t ha^{-1}	5.05 (25)^{e}	6.52 (42)^{f}	9.82 (96)^{e}	3.32 (10.5)^{e}	4.30 (18)^{g}	5.14 (25.9)^{g}
Maize stover mulch @ 5 t ha^{-1}	7.91 (62)^{c}	10.51 (110)^{d}	14.98 (224)^{c}	5.27 (27.3)^{c}	5.99 (35.4)^{e}	7.69 (58.6)^{e}
Leucaena twigs mulch @ 5 t ha^{-1}	9.72 (94)^{b}	12.27 (150)^{c}	18.23 (332)^{b}	6.69 (44.3)^{b}	8.03 (64)^{c}	11.19 (124.6)^{c}
Paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	6.04 (36)^{d}	8.40 (70)^{e}	12.75 (162)^{d}	3.95 (15.1)^{d}	4.89 (23.4)^{f}	6.51 (41.8)^{f}
Maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	8.22 (67)^{c}	10.79 (116)^{d}	15.70 (246)^{c}	5.44 (29.0)^{c}	7.18 (51.1)^{d}	9.77 (95)^{d}

* DAS = Days After Sowing

Treatment means with similar superscripted letters within a column are not significantly different at $p<0.05$ according to Turkey's honestly significant difference test

TABLE 2 Effect of different mulches on plant height (cm), number of branches $plant^{-1}$ and number of nodules $plant^{-1}$ of chickpea

	Plant height (cm)			Branches	Nodules
Treatment	30 DAS*	60 DAS	90 DAS	(no. $plant^{-1}$)	(no. $plant^{-1}$)
Without mulch	17.7^{e}	29.7^{d}	41.0^{d}	7.33^{d}	7.5^{f}
Dust mulch	19.0^{d}	31.0^{c}	52.9^{c}	11.0^{cd}	8.7^{e}
Paddy straw mulch @ 5 t ha^{-1}	24.3^{b}	34.2^{b}	58.0^{ab}	15.3^{ab}	18.2^{b}
Maize stover mulch @ 5 t ha^{-1}	21.3^{c}	31.7^{c}	53.6^{bc}	12.7^{bc}	12.4^{d}
Leucaena twigs mulch @ 5 t ha^{-1}	23.2^{b}	34.0^{b}	55.1^{bc}	13.3^{abc}	17.3^{b}
Paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	26.3^{a}	36.0^{a}	59.0^{a}	17.0^{a}	19.4^{a}
Maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	21.6^{c}	33.3^{b}	54.3^{bc}	13.0^{abc}	15.7^{c}

*DAS=Days after sowing

Treatment means with superscripted letters within a column are not significantly different at $P<0.05$ according to Tukey's honestly significant difference test

TABLE 3 Effect of different mulches on yield attributes and yield of chickpea

Treatment	Yield attributes			Yield (kg ha^{-1})			Harvest Index (%)	Soil moisture (%) at 60 DAS
	Pods (no. plant^{-1})	Grains (no. pod^{-1})	100 seed weight (g)	Seed	Stover	Biological		
Without mulch	29.3^{f}	1.3^{c}	25.2^{b}	988^{g}	1570^{f}	2558^{g}	38.6^{a}	5.33^{f}
Dust mulch	40.7^{e}	1.6^{ab}	26.2^{b}	1104^{f}	1778^{e}	2882^{f}	38.3^{a}	7.67^{e}
Paddy straw mulch @ 5 t ha^{-1}	55.0^{b}	1.7^{a}	28.5^{a}	1567^{b}	2429^{b}	3997^{b}	39.2^{a}	16.7^{a}
Maize stover mulch @ 5 t ha^{-1}	43.7^{de}	1.5^{b}	28.0^{a}	1200^{e}	1908^{d}	3103^{e}	38.7^{a}	13.3^{bc}
Leucaena twigs mulch @ 5 t ha^{-1}	49.0^{c}	1.6^{ab}	27.5^{a}	1402^{c}	2314^{b}	3717^{c}	37.7^{a}	11.0^{d}
Paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	60.7^{a}	1.7^{a}	29.2^{a}	1749^{a}	2606^{a}	4355^{a}	40.2^{a}	13.7^{b}
Maize stover mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1}	46.7^{cd}	1.5^{b}	28.0^{a}	1312^{d}	2112^{c}	3424^{d}	38.3^{a}	12.0^{c}

Treatment means with similar superscripted letters within a column are not significantly different at $P<0.05$ according to Tukey's honestly significant difference test

3.4 | Effect On Soil Moisture

Mulching treatments significantly influenced mid-season surface soil moisture content at 60 DAS (Table 3). The maximum mid-season surface soil moisture (16.7%) was recorded under paddy straw mulch @ 5 t ha^{-1} at 60 DAS, while the minimum was observed in without mulch. Soil moisture under paddy straw @ 5 t ha^{-1} was significantly higher than all other treatments, indicating the superior moisture-conserving ability of paddy straw mulch. This improvement may be attributed to the formation of a uniform, continuous mat over the soil surface, which reduces direct exposure to solar radiation, minimizes wind velocity at the soil-atmosphere interface, and suppresses evaporative water losses (Pawar *et al*., 2019; Ramos *et al*., 2024). Similar enhancements in soil moisture retention under straw mulching have been widely reported, particularly during mid-season stages when evaporative demand is high (Kumari *et al.*, 2024). In contrast, the lowest mid-season surface soil moisture content under the treatment without mulch may be due to rapid evaporation from the exposed soil surface, leading to faster depletion of soil water reserves. The absence of surface cover leads to greater temperature fluctuations and accelerates soil drying, especially under warm, dry conditions (Meshram *et al.*, 2022).

4 | Limitations Of The Study

While the present study provides useful insights into the effectiveness of crop residue mulching on weed suppression, soil moisture conservation, and chickpea productivity, certain limitations should be acknowledged. The experiment was conducted during a single cropping season at one location, and therefore the results may not fully capture inter-annual climatic variability or site-specific soil-crop interactions; consequently, extrapolation of findings to other agro-ecological regions should be done cautiously. In addition, practical constraints associated with residue mulching may limit large-scale adoption by farmers. Crop residues often serve as an important source of livestock feed, and their competing use for fodder can restrict availability for mulching. Dry residue mulches may also attract termites or other pests, potentially creating management challenges in farmers' fields. The application and uniform spreading of mulches require additional labour, and the unavailability or high cost of manpower during peak agricultural operations can discourage their use. Furthermore, increasing the utilization of crop residues for alternative purposes, such as biofuel or energy production, reduces the quantity available for in-situ conservation practices. These socioeconomic and operational factors should be considered when interpreting the results and highlight the need for multi-location, multi-season studies that integrate agronomic effectiveness with practical feasibility under real farming conditions.

5 | CONCLUSIONS

The present study demonstrated that mulching significantly influenced weed suppression, crop growth, and chickpea yield under rainfed conditions in Varanasi, Uttar Pradesh, during the rabi season of 2022-23. Among the treatments, paddy straw mulch @ 5 t ha^{-1} was most effective in reducing total weed density, weed dry biomass, and conserving mid-season surface soil moisture during critical growth stages of chickpea (peak flowering or early pod development stage). However, the combined application of paddy straw mulch @ 2.5 t ha^{-1} + *Leucaena* twigs mulch @ 2.5 t ha^{-1} resulted in superior performance with respect to plant height, number of branches, nodules per plant, seed yield, and harvest index compared to other treatments evaluated. Based on the findings of this single-season, single-location study, the integrated mulching approach using both organic residues showed promising potential to enhance chickpea productivity under rainfed conditions similar to those at the experimental site. However, further multi-season and multi-location studies are required to validate the consistency and wider applicability of these results under diverse agro-ecological conditions.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Data will be made available on request.

AUTHOR'S CONTRIBUTION

Kareti Harika: Conceptualization, writing original manuscript; Sudhir Kumar Rajpoot: Data analysis; S.K. Verma: Software; Udaya Lakshmi D: Formal analysis; Ambikesh Tripathi: methodology; Dinesh Jinger: Writing and reviewing.

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