



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(6): 1381-1386
Received: 14-04-2026
Accepted: 20-05-2026

Aishwarya Golshetti
Department of Agronomy, College
of Agriculture, V C Farm, Mandya,
University of Agricultural Science,
Bangalore, Karnataka, India

Yogananda SB
Department of Agronomy, College
of Agriculture, V C Farm, Mandya,
University of Agricultural Science,
Bangalore, Karnataka, India

Ananthakumar MA
Department of Soil Science and
Agricultural Chemistry, Water
Technology Centre Zonal
Agricultural Research Station V C
Farm, Mandya, University of
Agricultural Science, Bangalore,
Karnataka, India

MN Thimmegowda
Department of Agricultural
Meteorology, GKVK, University of
Agricultural Science, Bangalore,
Karnataka, India

P Thimmegowda
Zonal Agricultural Research
Station, V C Farm, Mandya,
University of Agricultural Science,
Bangalore, Karnataka, India

Shivashankar K
Carbon Department, Growindigo
Pvt. Ltd., New Delhi, India

Corresponding Author:
Aishwarya Golshetti
Department of Agronomy, College
of Agriculture, V C Farm, Mandya,
University of Agricultural Science,
Bangalore, Karnataka, India

Mulching and diversified cropping on improvement of nutrient uptake and soil moisture in a rainfed maize-based system

Aishwarya Golshetti, Yogananda SB, Ananthakumar MA, MN Thimmegowda, P Thimmegowda and Shivashankar K

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i6q.6483>

Abstract

Efficient nutrient acquisition and soil-moisture conservation are essential for improving the productivity and resilience of rainfed maize-based cropping systems. A field experiment was conducted during 2024 and 2025 to evaluate the effects of residue mulching and diversified maize-legume cropping systems on nitrogen (N), phosphorus (P) and potassium (K) uptake, soil moisture, maximum water-holding capacity and bulk density. The experiment was conducted in a split-plot design with three replications. Mulching constituted the main-plot treatment, comprising mulched (M_1) and non-mulched (M_2) conditions, while six maize- and legume-based cropping systems were assigned to subplots: dhaincha followed by maize (S_1), dhaincha followed by maize + green gram (S_2), maize + green gram (S_3), green gram followed by maize (S_4), maize followed by field bean (S_5), and maize + green gram followed by field bean (S_6). Mulching significantly increased total N, P and K uptake in both years. Total N uptake under M_1 was 159.6 and 155.7 kg ha⁻¹ in 2024 and 2025, respectively, compared with 142.1 and 133.4 kg ha⁻¹ under M_2 . Similarly, total P uptake under M_1 was 43.7 and 43.9 kg ha⁻¹, while total K uptake was 156.3 and 154.4 kg ha⁻¹ in the two years. Among cropping systems, S_6 recorded the highest total N uptake, P uptake and K uptake. Mulching also increased soil moisture at harvest from 6.76% under M_2 to 7.53% under M_1 . The M_1S_6 combination produced the highest numerical nutrient uptake, although most interaction effects were statistically non-significant. The results indicate that residue mulching combined with maize-pulse diversification can improve nutrient acquisition and soil-moisture conservation in rainfed production systems.

Keywords: Maize, mulching, green gram, field bean, nutrient uptake, soil moisture, cropping system, rainfed agriculture

1. Introduction

Maize-based cropping systems are important components of rainfed agriculture, but their productivity is frequently constrained by irregular rainfall, low soil-moisture availability, nutrient losses and declining soil quality. These constraints are particularly severe in semi-arid regions, where rainfall is concentrated in a limited number of events and crop demand often coincides with dry periods. Improving nutrient-use efficiency and conserving soil moisture are therefore central to the development of productive and climate-resilient cropping systems.

Crop-residue mulching is an important conservation practice for reducing direct soil evaporation, moderating soil temperature, improving infiltration and protecting the soil surface from raindrop impact. By maintaining a more favourable soil-water environment, mulching can enhance nutrient diffusion and root activity. Previous studies have reported increased nitrogen, phosphorus and potassium uptake in maize and other crops under mulched conditions, although the magnitude of the response depends on mulch material, soil type, nutrient management and rainfall conditions. Mulching may also influence nutrient cycling through the gradual decomposition of organic residues. Residues can provide carbon substrates for soil microorganisms and may reduce nutrient losses through runoff, erosion and leaching. Improved soil moisture under mulch can enhance nitrogen uptake because nitrogen movement and acquisition are closely associated with water availability. Phosphorus uptake may also improve when moisture conditions support root growth and phosphorus diffusion in the soil solution.

Diversification with legumes provides an additional pathway for improving nutrient acquisition and system sustainability. Green gram and field bean can contribute biologically fixed nitrogen, increase root activity and improve the availability of residual nutrients for succeeding crops. Legume-based rotations may also increase soil biological activity and improve the quantity and quality of crop residues returned to the soil. However, the benefits of legumes depend on crop combination, sequence, duration, biomass production and competition between component crops. Although mulching and legume diversification are individually recognised as beneficial practices, their combined effects under rainfed maize-based systems require location-specific evaluation. Information is particularly limited for systems involving maize, green gram, dhaincha and field bean in the semi-arid regions of southern Karnataka. Therefore, the present study evaluated the effects of residue mulching and maize-legume cropping systems on system N, P and K uptake and selected soil physical properties during 2024 and 2025.

The objectives of the study were to

1. Assess the effect of mulching on system total N, P and K uptake.
2. Determine the influence of mulching and cropping systems on soil moisture, maximum water-holding capacity and bulk density.
3. Identify the most promising treatment combination for improving nutrient use and soil-moisture conservation under rainfed conditions.

2. Materials and Methods

2.1 Experimental site

The experiment was conducted during 2024 and 2025 under rainfed conditions at a farmer's field in the Bankanahalli micro-watershed, Dudda sub-watershed, Mandya district, Karnataka, India. The experimental site was located at 12.60447° N latitude and 76.766249° E longitude, at an altitude of 678 m above mean sea level.

The region falls within the Southern Dry Zone of Karnataka and is characterised by a semi-arid climate with distinct summer, kharif and rabi seasons. The soils of the region are predominantly red sandy loam to red loam, although the experimental site contained a sandy clay loam soil. The field was gently sloping and well drained.

2.2 Initial soil properties

The soil contained 61.45% sand, 4.60% silt and 33.95% clay and was classified as sandy clay loam. The soil pH was 8.3, and electrical conductivity was 0.29 dS m⁻¹. Initial soil organic carbon was 4.2 g kg⁻¹. Available nitrogen, phosphorus and potassium were 174.41, 43.70 and 128.68 kg ha⁻¹, respectively.

Exchangeable calcium and magnesium were 12.0 and 1.3 cmol(p⁺) kg⁻¹, respectively. DTPA-extractable iron, manganese, copper and zinc were 12.58, 7.40, 1.92 and 1.452 mg kg⁻¹, respectively. Initial bulk density, maximum water-holding capacity and soil moisture content were 1.15 g cm⁻³, 40.6% and 6.0%, respectively.

2.3 Experimental design and treatments

The experiment was laid out in a split-plot design with three replications. Mulching was assigned to the main plots, and cropping systems were assigned to the subplots.

The main-plot treatments were:

- **M₁**: With residue mulching.
- **M₂**: Without residue mulching.

The subplot treatments were:

- **S₁**: Dhaincha followed by maize.
- **S₂**: Dhaincha followed by maize + green gram.
- **S₃**: Maize + green gram.
- **S₄**: Green gram followed by maize.
- **S₅**: Maize followed by field bean.
- **S₆**: Maize + green gram followed by field bean.

The mulched treatment consisted of rice-straw mulching during the kharif season and retention of maize and green gram residues during the rabi season. The non-mulched treatment did not receive surface residue mulch.

2.4 Crop management

The field was prepared using primary tillage followed by harrowing and levelling. Maize was established at 60 cm × 20 cm spacing. Green gram was sown at 60 cm × 10 cm in sole stands and at 30 cm × 10 cm in intercropping arrangements. Field bean was planted at 30 cm × 10 cm. Dhaincha was grown as a green-manure crop before maize.

Farmyard manure and recommended fertiliser doses were applied uniformly to the experimental plots. Nitrogen was applied in split doses, whereas phosphorus and potassium were applied according to the recommended package of practices. Pulse crops were inoculated with suitable biofertiliser cultures where applicable. Weed control, gap filling and plant-protection operations were performed uniformly across treatments.

2.5 Determination of nutrient uptake

At crop maturity, grain and stover samples were collected separately from each plot. Samples were dried, weighed and ground for chemical analysis. Nitrogen concentration was determined using the Kjeldahl method. Phosphorus concentration was determined using the vanadomolybdate yellow-colour method, and potassium concentration was determined using flame photometry.

Nutrient uptake was calculated using the following equation:

$$\text{Nutrient uptake} = \frac{\text{Nutrient concentration} \times \text{Dry matter yield}}{100}$$

Grain and stover uptake were calculated separately and then added to obtain total system uptake. The results were expressed in kg ha⁻¹.

2.6 Soil-moisture determination

Soil samples were collected at harvest from the surface soil layer. Soil moisture content was determined gravimetrically as:

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh weight of soil sample} - \text{dry weight of soil sample}}{\text{Dry weight of the soil sample}} \times 100$$

2.7 Maximum water-holding capacity

Maximum water-holding capacity was determined by saturating the soil sample with water and measuring the quantity of water retained after drainage. The value was expressed as a percentage of oven-dry soil weight.

2.8 Bulk density

Bulk density was estimated using a Keen's cup. The soil sample was oven-dried at 105 °C until a constant weight was obtained. Bulk density was calculated as:

$$\text{Bulk density} = \frac{\text{Oven} - \text{dry soil mass}}{\text{Volume of the Keen's cup}}$$

Bulk density was expressed in g cm^{-3} .

2.9 Statistical analysis

The data were analysed using analysis of variance appropriate for a split-plot design. The significance of treatment effects was tested using Fisher's F-test at the 5% probability level. Standard error of the mean and critical difference values were calculated for comparing treatment means. Where the interaction was non-significant, treatment means were interpreted based on the main effects.

3. Results

3.1 Nitrogen uptake

Mulching significantly increased system nitrogen uptake during both years of experimentation. In 2024, mulched plots recorded 106.8 kg ha^{-1} N uptake in grain, 52.8 kg ha^{-1} in stover and 159.6 kg ha^{-1} as total uptake. The corresponding values under non-mulched plots were 97.4, 44.7 and 142.1 kg ha^{-1} , respectively (Table 1).

A similar trend was observed in 2025. Mulched plots recorded 99.7, 51.6 and 155.7 kg ha^{-1} N uptake in grain, stover and total biomass, respectively, compared with 92.8, 40.6 and 133.4 kg ha^{-1} under non-mulched conditions. The increase in total N uptake due to mulching was 12.3% in 2024 and 16.7% in 2025.

Among the cropping systems, S_6 recorded the highest total N uptake, with 183.9 kg ha^{-1} in 2024 and 178.8 kg ha^{-1} in 2025. Maize-Fieldbean ranked second, with 159.7 and 157.3 kg ha^{-1} , respectively. The lowest total N uptake occurred under Dhaincha-Maize, with 118.6 kg ha^{-1} in 2024 and 105.3 kg ha^{-1} in 2025.

The interaction between mulching and cropping system was not significant for total N uptake. Nevertheless, Maize+Greengram-Fieldbean (M_1S_6) with crop residue mulching recorded the highest numerical values, with total uptake of 191.8 kg ha^{-1} in 2024 and 186.0 kg ha^{-1} in 2025. The corresponding values under Maize+Greengram-Fieldbean (M_2S_6) without crop residue mulching were 176.0 and 171.5 kg ha^{-1} .

3.2 Phosphorus uptake

Mulching significantly improved phosphorus uptake in both years. In 2024, total P uptake was 43.7 kg ha^{-1} under with residue mulching plots and 37.5 kg ha^{-1} under without residue mulching plots. In 2025, the corresponding values were 43.9 and 35.8 kg ha^{-1} (Table 2).

In the mulched treatment during 2024, grain and stover P uptake were 20.2 and 23.5 kg ha^{-1} , respectively. Under non-mulched conditions, the corresponding values were 17.8 and 19.7 kg ha^{-1} . In 2025, mulching with crop residue recorded 20.1 kg ha^{-1} in grain and 23.7 kg ha^{-1} in stover, whereas non-mulched recorded 17.3 and 18.4 kg ha^{-1} .

The Maize + green gram followed by field bean cropping system recorded the highest total P uptake, with 45.7 kg ha^{-1} in 2024 and 44.7 kg ha^{-1} in 2025. The lowest values were observed under Dhaincha followed by Maize, with 34.0 and 31.6 kg ha^{-1} , respectively.

The interaction effect was not significant for P uptake in either year. However, M_1S_6 recorded the highest numerical values of total P uptake, with 48.0 kg ha^{-1} in 2024 and 46.9 kg ha^{-1} in 2025.

3.3 Potassium uptake

Mulching increased potassium uptake in both years. In 2024, mulching with crop residue recorded 50.9 kg ha^{-1} K uptake in

grain, 105.4 kg ha^{-1} in stover and 156.3 kg ha^{-1} as total uptake. The corresponding values under non-mulched plots were 46.0, 92.6 and 138.6 kg ha^{-1} (Table 3).

In 2025, total K uptake was 154.4 kg ha^{-1} under mulching with crop residue and 126.9 kg ha^{-1} under non-mulched plots. Grain and stover K uptake under mulching with crop residue were 49.7 and 104.7 kg ha^{-1} , respectively, compared with 43.6 and 83.3 kg ha^{-1} under non-mulched plots.

Among cropping systems, S_6 recorded the highest total K uptake, with 185.8 kg ha^{-1} in 2024 and 173.1 kg ha^{-1} in 2025. S_5 recorded the second-highest values, with 165.9 and 160.4 kg ha^{-1} , respectively. Dhaincha followed by Maize had the lowest total K uptake, with 117.7 and 111.6 kg ha^{-1} .

The interaction effect was not significant for total K uptake. However, Maize+Greengram-Fieldbean (M_1S_6) with crop residue mulching recorded the highest numerical uptake, with 192.7 kg ha^{-1} in 2024 and 183.7 kg ha^{-1} in 2025.

3.4 Soil moisture content

Mulching significantly increased soil moisture at harvest. The soil-moisture content was 7.53% under mulching with crop residue, compared with 6.76% under non-mulched plots (Table 4).

Cropping systems also significantly influenced soil moisture. Dhaincha followed by Maize recorded the highest value at 8.63%, followed by Dhaincha followed by Maize+greengram at 7.93% and S_6 at 7.27%. The lowest value was observed under Maize+greengram (S_3) at 6.00%.

The interaction between mulching and cropping system was significant. Dhaincha followed by Maize (M_1S_1) with crop residue mulching recorded the highest soil-moisture content at 10.28%, while Maize +greengram (M_2S_3) with crop residue mulching recorded the lowest value at 5.97%.

3.5 Maximum water-holding capacity

Mulching did not significantly influence maximum water-holding capacity. The values under with crop residue mulching and non-mulched were 44.95 and 44.90%, respectively (Table 4).

Cropping systems significantly affected maximum water-holding capacity. Maize-greengram (S_4) recorded the highest value at 49.16%, whereas Maize+greengram (S_3) recorded the lowest value at 40.65%. The interaction treatment Maize-greengram (M_1S_4) with crop residue mulching recorded the highest value at 50.37%, while Maize+greengram followed by field bean with crop residue mulching (M_1S_5) recorded the lowest value at 38.46%.

3.6 Bulk density

Bulk density was not significantly influenced by mulching. The values were 1.15 g cm^{-3} under with crop residue mulching and 1.23 g cm^{-3} under non-mulched (Table 4).

Significant differences were observed among cropping systems. The lowest bulk density was recorded under Maize+greengram (S_3) at 1.06 g cm^{-3} , while the highest value occurred under Maize-greengram (S_4) at 1.30 g cm^{-3} . The interaction effect was not significant, although Maize+greengram (M_1S_3) with crop residue mulching recorded a comparatively low bulk density of 1.08 g cm^{-3} .

4. Discussion

4.1 Effect of mulching on nutrient uptake

The consistent increase in N, P and K uptake under mulching indicates that residue retention improved the soil environment for crop nutrient acquisition. Mulch protects the soil surface, reduces

evaporation and improves the continuity of soil moisture. This is particularly important for nitrogen because nitrogen uptake depends on both root activity and the movement of nitrate and ammonium through the soil solution.

The results are consistent with earlier findings that mulch can increase N uptake by improving soil-water availability and reducing nutrient losses (Kader *et al.*, 2017) [3]. In rainfed maize, higher soil moisture under mulch can improve nitrate uptake and reduce losses associated with volatilisation and runoff (Demo *et al.*, 2024; Wu *et al.*, 2024) [2, 9]. Similar increases in N, P and K uptake have been reported under legume or organic mulching systems (Liu *et al.*, 2023; Wang *et al.*, 2024a) [4, 7].

The response of phosphorus to mulching may be related to greater root growth and improved microbial activity. Moisture is important for phosphorus diffusion because phosphorus moves slowly through the soil. Improved soil-water conditions can therefore increase the supply of phosphorus to roots. Residue decomposition may also stimulate microbial processes that contribute to phosphorus mobilisation.

Potassium uptake was strongly improved by mulching, particularly in 2025. Potassium is relatively mobile in the soil compared with phosphorus and can be lost through leaching or runoff. Surface residue may reduce these losses and allow more potassium to remain available for crop uptake. The high stover K uptake also reflects the role of maize biomass as a major sink for potassium.

4.2 Effect of cropping systems on nutrient uptake

The superior performance of S₆ for N, P and K uptake demonstrates the value of combining maize, green gram and field bean within a diversified system. The system included a cereal and two legumes, providing variation in rooting depth, nutrient demand, crop duration and residue quality.

Higher N uptake under S₆ may be related to biological nitrogen fixation by the legume components and improved residual nitrogen availability for maize (Peoples & Herridge, 1990; Murphy-Bokern *et al.*, 2021) [6, 5]. However, total system uptake should not be interpreted as direct evidence that all nitrogen was fixed biologically. Quantifying biological nitrogen fixation would require additional methods such as nitrogen-difference, isotope-dilution or natural-abundance approaches.

The improved P uptake under S₆ may be associated with greater root density, rhizosphere activity and organic-acid release by the legume crops. Legume residues and root exudates can stimulate microbial processes and increase the availability of sparingly soluble phosphorus. The higher K uptake under S₆ was probably related to greater total biomass production and greater nutrient demand across the combined crop sequence.

The lower nutrient uptake under S₁ may be explained by the shorter or less diversified nutrient-acquisition pathway during the evaluated system period. Although dhaincha can contribute substantial biomass and nitrogen, a single dhaincha-maize sequence may not provide the same cumulative nutrient uptake as a system containing both green gram and field bean (Adeleke & Haruna, 2012) [1].

4.3 Interaction between mulching and cropping systems

The highest numerical values for all three nutrients were generally

recorded under M₁S₆. This result suggests that residue retention and crop diversification may act through complementary mechanisms. Mulching improves moisture and reduces nutrient losses, whereas legumes increase biological activity and may improve nitrogen and phosphorus cycling.

However, the interaction effects were mostly non-significant. Therefore, the statistical evidence supports the independent effects of mulching and cropping system more strongly than a confirmed synergistic interaction. The M₁S₆ combination may still be recommended as a promising integrated treatment, but claims of interaction should be restricted to variables for which the analysis showed statistical significance.

4.4 Effect of mulching and cropping systems on soil moisture

The higher soil moisture under mulching confirms the role of surface residues in reducing evaporative loss (Kader *et al.*, 2017; Demo *et al.*, 2024) [3, 2]. The 11.4% relative increase in soil moisture under M₁ compared with M₂ is agronomically relevant in rainfed agriculture, where small changes in soil-water availability can influence nutrient uptake and crop growth.

The highest soil moisture under M₁S₁ may be associated with the combined effects of residue cover and the preceding dhaincha crop. Dhaincha contributes biomass and may improve surface protection and soil aggregation. However, the higher soil moisture under S₁ did not correspond to the highest nutrient uptake, indicating that moisture conservation must be considered alongside crop biomass, root activity and nutrient demand.

The low soil moisture under Maize+greengram without crop residue management (M₂S₃) may have resulted from the absence of surface mulch combined with high water demand from the maize-green gram association. Intercropping can increase total resource use and may reduce residual soil moisture when rainfall is inadequate (Wang *et al.*, 2024b) [8].

4.5 Maximum water-holding capacity and bulk density

The absence of a significant main-plot effect of mulching on maximum water-holding capacity suggests that one or two seasons of residue retention may be insufficient to produce measurable changes in this relatively stable soil property. Changes in water-holding capacity generally depend on longer-term accumulation of soil organic matter and improvement in aggregate structure.

The significant variation among cropping systems indicates that crop sequence may influence soil physical properties through differences in root growth and residue return. The high water-holding capacity under Maize-Fieldbean may be related to greater root-derived organic matter or changes in pore-size distribution. Nevertheless, the contrasting values among treatments should be interpreted cautiously and verified through repeated soil sampling.

Bulk density showed a numerical reduction under mulching but the difference was not significant. This indicates that residue retention had begun to improve soil physical condition but that the duration of the experiment may have been too short to produce a statistically measurable change. The lower bulk density under S₃ suggests a potentially favourable soil structure, although this treatment did not produce the highest soil moisture or nutrient uptake.

Table 1: System grain, straw and total uptake of nitrogen as influenced by mulching and cropping system

Treatments	N uptake (kg/ha)					
	Grain	Stover	Total	Grain	Stover	Total
	2024			2025		
	MAIN PLOT					
M ₁	106.8	52.8	159.6	99.7	51.6	155.7
M ₂	97.4	44.7	142.1	92.8	40.6	133.4
S.Em. ±	0.6	1.7	2.3	1.1	0.7	1.8
C. D. @ 5%	3.5	NS	13.7	6.6	4.0	11.0
	SUB PLOT					
S ₁	82.5	36.1	118.6	57.7	34.1	105.3
S ₂	97.8	50.1	147.8	98.3	48.9	147.3
S ₃	95.1	47.9	142.9	90.1	47.0	137.1
S ₄	100.1	52.0	152.2	95.3	46.4	141.7
S ₅	112.5	47.2	159.7	111.4	45.8	157.3
S ₆	124.5	59.4	183.9	124.5	54.3	178.8
S.Em. ±	2.8	1.3	3.2	3.8	1.4	4.4
C. D. @ 5%	8.3	3.8	9.5	11.3	4.1	12.9
	INTERACTION					
M ₁ S ₁	88.6	39.5	128.1	52.9	39.7	119.4
M ₁ S ₂	101.7	53.6	155.3	104.0	52.3	156.3
M ₁ S ₃	97.9	51.8	149.7	94.7	49.6	144.4
M ₁ S ₄	107.1	56.2	163.2	103.2	54.7	157.9
M ₁ S ₅	117.5	51.8	169.3	116.6	53.8	170.4
M ₁ S ₆	128.0	63.8	191.8	126.7	59.3	186.0
M ₂ S ₁	76.4	32.7	109.1	62.6	28.6	91.2
M ₂ S ₂	93.9	46.5	140.3	92.6	45.6	138.2
M ₂ S ₃	92.3	43.9	136.2	85.5	44.4	129.9
M ₂ S ₄	93.2	47.9	141.1	87.4	38.1	125.6
M ₂ S ₅	107.5	42.5	150.0	106.2	37.8	144.1
M ₂ S ₆	121.1	54.9	176.0	122.2	49.3	171.5
S.Em.±	3.96	1.84	4.56	5.42	1.95	6.20
C. D. @ 5%	NS	NS	NS	NS	5.74	NS

Table 2: System grain, straw and total uptake of phosphorus as influenced by mulching and cropping system

Treatments	P uptake (kg/ha)					
	Grain	Stover	Total	Grain	Stover	Total
	2024			2025		
	MAIN PLOT					
M ₁	20.2	23.5	43.7	20.1	23.7	43.9
M ₂	17.8	19.7	37.5	17.3	18.4	35.8
S.Em. ±	0.4	0.9	0.9	0.4	0.3	0.7
C. D. @ 5%	2.4	5.6	5.8	2.2	1.9	4.1
	SUB PLOT					
S ₁	16.3	17.7	34.0	14.4	17.2	31.6
S ₂	19.3	22.5	41.8	19.8	22.6	42.4
S ₃	18.9	21.8	40.6	18.2	22.4	40.6
S ₄	18.7	23.2	41.9	18.0	21.7	39.7
S ₅	19.2	20.2	39.5	19.7	20.0	39.8
S ₆	21.6	24.2	45.7	22.3	22.5	44.7
S.Em. ±	1.0	1.0	1.6	0.8	1.0	1.5
C. D. @ 5%	2.8	2.8	4.8	2.4	2.9	4.5
	INTERACTION					
M ₁ S ₁	18.1	19.7	37.9	16.6	20.5	37.1
M ₁ S ₂	20.7	24.9	45.6	21.6	24.7	46.4
M ₁ S ₃	20.0	23.2	43.2	19.7	23.1	42.8
M ₁ S ₄	20.1	25.7	45.8	19.8	26.4	46.2
M ₁ S ₅	20.0	21.4	41.4	20.3	23.4	43.7
M ₁ S ₆	22.2	25.8	48.0	22.7	24.2	46.9
M ₂ S ₁	14.5	15.7	30.2	12.2	14.0	26.2
M ₂ S ₂	17.8	20.1	37.9	18.0	20.5	38.5
M ₂ S ₃	17.7	20.4	38.1	16.8	21.6	38.4
M ₂ S ₄	17.2	20.7	37.9	16.2	17.0	33.2
M ₂ S ₅	18.5	19.0	37.5	19.1	16.7	35.8
M ₂ S ₆	20.9	22.5	43.4	21.8	20.8	42.5
S.Em.±	1.35	1.36	2.32	1.14	1.41	2.16
C. D. @ 5%	NS	NS	NS	NS	NS	NS

Table 3: System grain, straw and total uptake of potassium as influenced by mulching and cropping system

Treatments	K uptake (kg/ha)					
	Grain	Stower	Total	Grain	Stower	Total
	2024			2025		
			MAIN PLOT			
M ₁	50.9	105.4	156.3	49.7	104.7	154.4
M ₂	46.0	92.6	138.6	43.6	83.3	126.9
S.Em. ±	0.6	3.5	4.1	1.0	0.9	1.6
C. D. @ 5%	3.8	NS	NS	5.9	5.3	9.6
	SUB PLOT					
S ₁	40.9	76.8	117.7	35.1	76.5	111.6
S ₂	48.0	94.0	142.0	48.1	91.7	139.8
S ₃	46.5	90.5	137.0	43.9	90.3	134.2
S ₄	45.8	90.4	136.2	43.8	80.9	124.7
S ₅	52.7	113.3	165.9	51.8	108.6	160.4
S ₆	56.9	128.9	185.8	57.1	116.0	173.1
S.Em. ±	1.7	1.3	2.4	1.4	2.1	2.3
C. D. @ 5%	5.1	4.0	7.0	4.1	6.2	6.9
	INTERACTION					
M ₁ S ₁	43.5	83.9	127.4	38.9	88.4	127.3
M ₁ S ₂	50.3	98.4	148.7	51.2	96.1	147.3
M ₁ S ₃	48.1	95.4	143.5	46.6	94.4	141.0
M ₁ S ₄	49.2	98.0	147.3	47.8	98.4	146.2
M ₁ S ₅	55.4	122.7	178.1	55.0	125.7	180.8
M ₁ S ₆	59.1	133.6	192.7	58.6	125.2	183.7
M ₂ S ₁	38.2	69.8	108.0	31.3	64.6	95.9
M ₂ S ₂	45.7	89.6	135.3	45.1	87.2	132.3
M ₂ S ₃	44.9	85.6	130.5	41.2	86.1	127.3
M ₂ S ₄	42.4	82.7	125.1	39.8	63.5	103.3
M ₂ S ₅	49.9	103.9	153.7	48.6	91.5	140.1
M ₂ S ₆	54.7	124.2	178.9	55.7	106.8	162.5
S.Em.±	2.47	1.91	3.34	1.97	2.99	3.30
C. D. @ 5%	NS	NS	NS	NS	8.83	9.74

4.3.4 Influence of mulching and cropping system soil physical parameters

Table 4: Soil moisture content, water holding capacity and bulk density as influenced by mulching and cropping system at final harvest

Treatments	Soil moisture content (%)	Maximum water holding capacity of soil (%)	Bulk density (mg m ⁻³)
	At harvest	At harvest	At harvest
	MAIN PLOT		
M ₁	7.53	44.95	1.15
M ₂	6.76	44.90	1.23
S.E.m. ±	0.11	0.70	0.01
C. D. @ 5%	0.64	NS	NS
	SUB PLOT		
S ₁	8.63	44.82	1.22
S ₂	7.93	46.74	1.16
S ₃	6.00	40.65	1.06
S ₄	6.19	49.16	1.30
S ₅	6.86	43.02	1.23
S ₆	7.27	45.17	1.16
S.E.m. ±	0.18	1.15	0.02
C. D. @ 5%	0.54	3.40	0.07
	INTERACTION		
M ₁ S ₁	10.28	45.96	1.16
M ₁ S ₂	8.28	46.23	1.09
M ₁ S ₃	6.03	42.01	1.08
M ₁ S ₄	6.06	50.37	1.25
M ₁ S ₅	7.00	38.46	1.21
M ₁ S ₆	7.54	46.68	1.09
M ₂ S ₁	6.98	43.69	1.27
M ₂ S ₂	7.57	47.25	1.23
M ₂ S ₃	5.97	39.29	1.04
M ₂ S ₄	6.33	47.95	1.35
M ₂ S ₅	6.73	47.57	1.25
M ₂ S ₆	6.99	43.67	1.22
S.E.m. ±	0.26	1.63	0.03
C. D. @ 5%	0.76	4.80	NS
Initial	6.0	40.6	1.15

5. Conclusion

Residue mulching significantly improved N, P and K uptake in the maize-based cropping systems during both 2024 and 2025. Mulching also increased soil moisture at harvest, confirming its role in reducing evaporative losses and improving the soil-water environment under rainfed conditions.

Among the cropping systems, maize + green gram followed by field bean (S₆) recorded the highest total N, P and K uptake in both years. The system also performed well when combined with mulching. The superior nutrient uptake under S₆ was probably associated with greater crop diversity, increased biomass production, legume-mediated nutrient cycling and improved utilisation of soil resources.

The interaction between mulching and cropping system was generally non-significant for nutrient uptake, although Maize+Greengram-Fieldbean (M₁S₆) with crop residue management produced the highest numerical values. Therefore, the results support the recommendation of residue mulching and diversified maize-legume cropping as complementary components of a climate-resilient rainfed production strategy, while recognising that their statistical interaction requires further multi-year evaluation.

The results also demonstrate that soil moisture responded more rapidly to management than maximum water-holding capacity and bulk density. Long-term experiments are required to determine whether continued residue retention can increase soil organic carbon, improve soil structure and produce measurable changes in water-holding capacity and bulk density.

6. Declarations

Author's contribution

Aishwarya Golshetti: carried out the studies and participated in drafting the manuscript. S B Yogananda and Ananthakumar M A planned and prepared the draft for research. M N Thimmegowda participated in the design of the study, Thimmegowda P, and Shivashankar K. performed the statistical analysis and mapping. All authors read and approved the final manuscript.

Funding

The author gratefully acknowledges the financial support provided by the Centre of Excellence on Watershed Management, the Government of Karnataka, and the World Bank.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data availability

The treatment means, standard errors and critical-difference values are presented in the manuscript. Replication-level observations and complete statistical-analysis files should be made available from the corresponding author upon reasonable request.

References

1. Adeleke RA, Haruna SY. Residual nitrogen contributions from grain legumes to the growth and development of succeeding maize crop. *Int J Agric Biol.* 2012;14(2):245-250.
2. Demo JF, Silva MA, Costa LF. Enhancing crop yield and conserving soil moisture with mulching techniques. *Front Agron.* 2024;5:1361697.
3. Kader MA, Islam MR, Haque MA, Rana MS. Mulching type-induced soil moisture and temperature effects on crop productivity. *Soil Till Res.* 2017;165:102-110.
4. Liu J, Wang X, Chen Y. Evaluating the influence of straw

mulching and legume intercropping on soil moisture and crop yield. *Front Plant Sci.* 2023;14:1280382.

5. Murphy-Bokern D, *et al.* Contribution, utilization, and improvement of legumes-driven biological nitrogen fixation in cropping systems. *Front Sustain Food Syst.* 2021;5:767998.
6. Peoples MB, Herridge DF. Biological nitrogen fixation: an efficient source of nitrogen for sustainable agricultural production? *Soil Biol Biochem.* 1990.
7. Wang X, Liu J, Chen Y. Effects of organic management on soil health and crop yield. *Agric Sci J.* 2024.
8. Wang X, Zhang Y, Li J. Diversified crop rotations improve crop water use and soil moisture retention. *Agric Rev.* 2024;45(2):113-123.
9. Wu X, Zhang Y, Li H. Plastic mulching enhances maize yield and water use efficiency in semiarid regions. *Agric Water Manag.* 2024;271:107850.