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RESEARCH ARTICLE

Bio-mulches on moisture and biological properties of soils under maize-legume sequence

Joy Kumar Dey[1*], Binoy Kumar Saren[2], Rajib Das[3], Ashim Debnath[4], Ardhendu Chakraborty[5] & Pramod Das[1]

[1]Krishi Vigyan Kendra-Sepahijala, Central Agricultural University, Latiacherra 799 103, Tripura, India
[2]Department of Agronomy, Institute of Agriculture, Visva Bharati University, Bolpur 731 236, West Bengal, India
[3]Krishi Vigyan Kendra-Khowai, Chebri 799 207, Tripura, India
[4]Department of Genetics and Plant Breeding, Faculty of Agricultural Sciences, Rajiv Gandhi University, Rono Hills, Doimukh 791 112, Arunachal Pradesh, India
[5]Krishi Vigyan Kendra-Dima Hasao, Halflong 788 819, Assam, India

*Correspondence email - joykumardey7@gmail.com

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Abstract

To find out the best combination of cropping sequence and level of mulching for growing of Rabi legumes in maize-legume sequence. The present field experiment was conducted during 2017-18 and 2018-19 at the Agricultural Farm of Institute of Agriculture, Visva Bharati, located in Sriniketan, West Bengal using split plot design (SPD) with three main plots as cropping system (CS$_1$: maize-chickpea; CS$_2$: maize-lentil; CS$_3$: maize-lathyrus) and five sub-plot as mulching (M$_0$: No mulch (residue removal); M$_1$: *In-situ* maize stalk mulch (MSM); M$_2$: MSM + water hyacinth (5 t ha^{-1}); M$_3$: MSM + paddy straw (5 t ha^{-1}); M$_4$: MSM + paddy straw (2.5 t ha^{-1}) + water hyacinth (2.5 t ha^{-1})) and the experiments were replicated four times. In the present study, we have formulated locally available bio-mulches for the efficient moisture conservation and improving soil microbial conditions for growing Rabi pulses (chickpea, lentil, lathyrus) after Kharif maize under zero tillage. Among the bio-mulches, highest soil microbial biomass carbon (SMBC) (196.87 and 200.59 µg g^{-1} soil) and dehydrogenase activity (DHA) (25.32 and 26.70 µg TPF hr^{-1} g^{-1}) were recorded at 0-15 cm soil under MSM + paddy straw (5 t ha^{-1}) mulch (M$_3$) and in cropping sequence, highest water use efficiency was showed by maize-lathyrus (CS$_3$) (1.33 and 1.37 kg ha^{-1} mm^{-1}) for 2017-18 and 2018-19 respectively under MSM + paddy straw (5 t ha^{-1}) mulch (M$_3$). Bio-mulches conserve soil moisture and improved the soil biological properties and gave higher water productivity and water use efficiency.

Keywords: bio-mulching; moisture; water use efficiency; zero tillage

Introduction

The agriculture sector remains the one the main component of economy in many developing nations including India (1). For the last 50 years, agriculture has shifted towards intensification, characterized by increased use of hybrid/high yielding variety (HYV) seeds, synthetic fertilizers and pesticides (2). In addition, global climate change has emerged as a critical and vulnerable concern for the existing agricultural systems, environmental stability and social well-being because of rapidly increasing population, intensified land use, introduction invasive diseases and pests have collectively threatened the sustainability of agricultural systems (3, 4). These factors contributing to elevate greenhouse gas emissions and disturbing the climatic stability have detrimental effects on soil health and crop productivity, raising concern for the long-term food and nutrition security (5).

The agriculture sector is still the main component of Indian economy, contributing 16.5 % of the national gross domestic product (GDP) as nearly 50 % of the Indian population relies on agriculture and allied sectors for their livelihood (6, 7). Green revolution is one of the significant achievements in Indian agriculture leading to tremendous improvement in food grain production (8). The production of food grains increased due to factors such as increased use of synthetic fertilizers and pesticides, HYV, irrigations, higher cropping intensity and better management practices (9). As a result, India has become leading producers of cereals (rice, wheat), pulses, sugarcane and cotton in the world (10). But over the last five decades, cereals production has witnessed substantial growth, pulses have lagged behind, leading to persistent shortfall in meeting the dietary needs of the country's population, forcing significant amount of import (11). Despite being the world's largest producer, importer and consumer of pulses, India's pulses yield remains low at 789 kg per hectare, compared to the required 1 ton per hectare for international competitiveness. Pulses play very crucial role in maintain soil fertility by fixing atmospheric nitrogen through *Rhizobium* ssp with symbiotic relationship and they are integral part of Indian cropping system due to their compatibility with crop rotation and mixtures (12, 13). Maize is one of those crops, which can be fit with various pulses in crop rotations. In the global maize scenario, India stands fourth in total cultivated land and seventh in production, this makes up around 4 % of the world's maize cultivating land area and 2 % of its production (14). Maize is one of the most important cereal crops of the Birbhum district of West Bengal, which is mostly cultivated under rainfed condition during Kharif season.

Although this region receives sufficient rainfall during the monsoon, uneven distribution often leads to moisture stress during the dry season (15). With an average of 175 cm of rainfall per year, runoff accounts for the majority of water loss. In West Bengal, over 80 % of rainfall occurs from May to October, leaving insufficient soil moisture during the remaining months for crop cultivation without irrigation. The lack of irrigation infrastructure exacerbates this challenge, particularly from November to April, when the state experiences a water scarcity phase (16). The region's sloping terrain causes surplus water to flow rapidly, increasing erosion risks. After Kharif crop harvesting, insufficient soil moisture limits Rabi crop cultivation, leading to large areas remaining fallow and thus lowering the cropping intensity (17). To address post-monsoon moisture stress and improve crop productivity, low-cost agronomic techniques like soil moisture conservation have been found effective. In this region, maize stalks are often burned or left unused, while abundant weeds and hedgerow species during the rainy season are challenging to control. These organic residues could be efficiently used as bio-mulches. Combining crop residue retention with zero tillage can enhance soil quality and resource use efficiency. Since tilling the land after the Kharif crop causes moisture loss, zero tillage is a practical way to preserve moisture while preserving energy and fostering soil health (18). Zero tillage has been shown to retains soil moisture, reduce cultivation costs and enable timely sowing of subsequent crops. It also ensures more effective use of water and inputs by reducing soil and land degradation (19). Furthermore, by maintaining surface residue and zero tillage, along with mulching, reduces soil water loss and helps to preserve residual soil moisture, which in turn helps to grow winter crops (20, 21). Research has consistently shown that combining mulching with varied tillage practices significantly improves water use efficiency and productivity in oilseed crops in eastern India (22). Zero tillage with surface mulch improves moisture infiltration, reduces erosion and enhances water use efficiency when compared to conventional tillage (23). Crop residues act as a barrier to evaporation, increasing moisture retention in the root zone (24).

This study examines how well mulching works as a moisture-conservation method for growing Rabi or pre-Rabi crops under zero tillage after maize cultivation. Mulching offers multiple advantages, from affordability to ease of adoption and is expected to recharge the soil profile during the rainy season. The residual moisture conserved through mulching could then support the second crop following maize in the post-monsoon season, while also helping control soil erosion and weed growth.

Materials and Methods

Study site and climate

The field experiment was conducted over two consecutive Rabi seasons (2017-18 and 2018-19) at the Agricultural Farm of the Institute of Agriculture, Visva Bharati, located in Sriniketan, West Bengal (23°68′N, 87°68′E, elevation 58.9 m from mean sea level). The region experiences a humid subtropical climate with a monsoonal rainfall pattern. The Kharif season is marked by heavy rainfall between June and September, followed by a relatively dry Rabi season.

During the cropping periods, total rainfall amounted to 715.1 mm in 2017-18 and 422.9 mm in 2018-19, with most precipitation concentrated in August 2017 and September 2018. Maximum temperatures were observed in March 2018 (35.35 °C) and September 2018 (33.8 °C), while January 2018 (8.21 °C) and December 2018 (11.35 °C) recorded the lowest. Mean relative humidity ranged from 76.58 to 79.62 % (morning) and 66.40 to 69.36 % (evening). Evaporation peaked in March of both years, exceeding 140 mm.

Soil characteristics

The experimental soil was sandy loam, with 59 % sand, 27 % clay and 14 % silt. The soil pH was slightly acidic, averaging 5.58-5.61 across 0-30 cm depth. Organic carbon content ranged from 0.40 to 0.46 %. The soil was low in available nitrogen but medium in phosphorus and potassium. Bulk density values varied slightly between 1.36 and 1.39 g cm^{-3} depending on the year and soil depth. A detailed soil profile is presented in Table 1.

Experimental design and treatments

The experiment was laid out in a split-plot design with three cropping systems as main plot treatments and five bio-mulch options as subplot treatments, replicated four times. The three cropping systems included maize-chickpea (CS_1), maize-lentil (CS_2) and maize-lathyrus (CS_3). The subplot treatments comprised five mulching levels: no mulch with residue removal (M_0), *in-situ* maize stalk mulch (M_1), maize stalk mulch combined with water hyacinth at 5 t ha^{-1} (M_2), maize stalk mulch with paddy straw at 5 t ha^{-1} (M_3) and maize stalk mulch with equal proportions of paddy straw and water hyacinth at 2.5 t ha^{-1} each (M_4). The experimental plots measured 6 × 3 m and a total of 60 plots were maintained throughout the study. This design allowed for the assessment of both main and interaction effects of cropping systems and mulching treatments under field conditions.

Soil sampling

Soil moisture

Soil moisture content was assessed at 30-day intervals using the gravimetric method. During Kharif, samples were collected at 15 and 15-30 cm depths; for Rabi crops, measurements were extended to 30-45 cm. Samples were oven-dried at 105 °C to a constant weight and moisture content (%) was calculated (25):

$$\text{Soil moisture (\%)} = \frac{\text{Weight of fresh soil-Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Table 1. Soil characteristics of the research field

Soil properties	2017		2018	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Soil pH	5.58	5.60	5.6	5.61
Organic carbon (%)	0.46	0.40	0.46	0.41
Available nitrogen (kg ha^{-1})	176.74	151.62	181.52	156.87
Available phosphorus (kg ha^{-1})	14.75	11.51	15.04	12.13
Available potassium (kg ha^{-1})	177.25	168.61	184.36	169.28
Bulk density (g cm^{-3})	1.37	1.39	1.36	1.39

(Note: % = percentage, kg ha^{-1} = kilogram per hectare, g cm^{-3} = gram per cubic centimetre)

Soil moisture stock

Moisture stock was calculated at flowering stages:

$$\text{Soil moisture stock (cm per 45 cm)} = \frac{\text{Soil moisture content (\%)}}{100} \times \text{Bulk density} \times \text{Depth}$$

Infiltration rate

Post-Rabi harvest, infiltration rate was measured using a double-ring infiltrometer (outer ring: 45 cm, inner ring: 30 cm diameter; 30 cm height) (25). The rings were inserted 5 cm into leveled soil and water was added to maintain a constant head. Readings were taken at 5- and 15-min intervals. Infiltration rate was calculated:

$$\text{Infiltration rate (cm min}^{-1}\text{)} = \frac{\text{Change in water level (cm)}}{\text{Time interval (minute)}} \times 60$$

Cumulative infiltration was obtained by summing successive infiltration values. The basic infiltration rate was recorded once a steady state was reached.

Bulk density and water holding capacity

Bulk density was determined at 0-15, 15-30 and 30-45 cm depths using the core method. Soil cores (6.4 cm length × 4.9 cm diameter) were oven-dried and bulk density was calculated:

Water holding capacity (WHC) was measured post-harvest at similar depths using the perforated can method (26).

$$\text{Bulk density (mg m}^{-3}\text{)} = \frac{\text{Mass}}{\text{Volume}}$$

Soil biological properties

Soil microbial biomass carbon (SMBC)

Soil microbial biomass carbon (SMBC) was determined using the chloroform fumigation method (27). Two subsamples, each weighing 10 g, were collected-one was fumigant with chloroform vapor in a vacuum desiccator for 24 hr, while the other served as a control without fumigation. After the fumigation process, residual chloroform was removed and the fumigated soil samples were extracted with 25 mL of 0.5 M K_2SO_4. The non-fumigated samples were similarly extracted and both sets of extracts were filtered by using Whatman No. 42 filter papers. Organic carbon in the extracts was determined using the digestion-titration method (28). Soil microbial biomass carbon was measured as the difference between the fumigant and non-fumigant samples, divided by the K_2SO_4efficiency factor (KEC = 0.38) and expressed in µg g^{-1} of soil (29).

Dehydrogenase activity (DHA)

Dehydrogenase activity (DHA) was assessed using the triphenyl tetrazolium chloride (TTC) reduction method (30). Air-dried soil was incubated with TTC and $CaCO_3$ at 37 °C for 24 hr. The resulting triphenyl formazan (TPF) was extracted with methanol and quantified spectrophotometrically at 485 nm. Results were expressed as µg TPF hr^{-1} g^{-1} of soil.

Plant growth and biomass

Plant growth observations were recorded periodically for both Kharif and rabi crops. For biomass determination, three plants were randomly selected per plot at 30-day intervals. Roots and shoots were separated, cleaned, oven-dried at 65 °C to constant weight and expressed in g m^{-2} (24).

Water use efficiency (WUE)

Water use efficiency was calculated as the ratio of seed yield to the product of evapotranspiration (ET) and crop coefficient (Kc) (25) :

$$\text{WUE (\%)} = \frac{\text{Seed yield (kg ha}^{-1}\text{)}}{\text{Evapo transpiration (ET)} \times \text{Kc}}$$

ET values were derived by summing daily ET over the entire crop period, using crop-specific Kc values from FAO-56.

Water productivity

Water Productivity (25) was computed based on total rainfall during the cropping period and expressed as:

$$\text{Water productivity} = \frac{\text{Yield of maize+Rabi crop (kg ha}^{-1}\text{)}}{\text{Rainfall received during (maize + Rabi crop) (mm)}} \times 10000$$

Statistical analysis

Data obtained from the study were statistically analysed in split plot design (SPD) using analysis of variance (ANOVA). However, the plant parameters for Rabi crops were analysed in randomized block design (RBD). The difference between the treatment mean were tested to their statistical significance with appropriate critical difference (CD) value at 5 % level of probability (31).

Results

Soil moisture dynamics

During the Kharif seasons (2017-18 and 2018-19), maize was uniformly grown and soil moisture was monitored at 0-15 cm, 15 -30 cm and 30-45 cm depths (Table 2). Across all growth stages, the highest moisture content was consistently observed at 30-45 cm. Moisture content declined progressively from sowing to harvest. In 2017, values ranged from 18.7-23.6 % (0-15 cm), 20.3-24.5 % (15-30 cm) and 24.4-25.3 % (30-45 cm); in 2018, from 18.5-24.7 %, 20.3-25.5 % and 24.6-25.3 % respectively. During the Rabi seasons, soil moisture content varied significantly (11.97-27.41 % in 2017-18 and 16.16-30.47 % in 2018-19), influenced by cropping systems and bio-mulch treatments. The highest variation occurred in the 0-15 cm and 15-30 cm depths. CS_1 (2017-18) and CS_3 (2018-19) maintained the highest moisture levels. Bio-

Table 2. Soil moisture content (%) during Kharif crop (maize)

Soil depth (cm)	2017-18				2018-19			
	At sowing	30 DAS	60 DAS	At harvest	At sowing	30 DAS	60 DAS	At harvest
0-15	23.6	20.8	19.6	18.7	24.7	21.8	20.2	18.5
15-30	24.5	22.3	21.1	20.3	25.5	22.4	21.0	20.3
30-45	25.3	25.1	24.5	24.4	25.3	25.1	24.8	24.6

(Note: DAS = days after sowing)

mulching significantly improved soil moisture retention, especially in the topsoil layer. The M_3 treatment (MSM (maize stalk mulch) + 5 t ha^{-1} paddy straw) recorded the highest moisture, followed by M_4 (MSM + 2.5 t ha^{-1} water hyacinth + 2.5 t ha^{-1} paddy straw), both outperformed the non-mulched treatments (M_0 and M_1).

Effect of cropping systems and bio-mulching on soil bulk density

Cropping systems had no significant influence on soil bulk density at either 0-15 cm or 15-30 cm depths during both Rabi seasons (2017-18 and 2018-19), with values remaining uniform across systems (Table 3). A consistent increase in bulk density with depth was observed across all treatments. In contrast, bio-mulch treatments significantly affected bulk density at both depths. The highest bulk densities were recorded under the no-mulch treatment (M_0), reaching 1.30 and 1.33 g cm^{-3} at 0-15 cm and 15-30 cm depths respectively in 2017-18 and 1.29 and 1.32 g cm^{-3} in 2018-19. The lowest bulk density was observed under the M_3 treatment (MSM + 5 t ha^{-1} paddy straw), measuring 1.25 g cm^{-3} at 0-15 cm in both years. Overall, mulching reduced bulk density, especially in surface soil, indicating improvement in soil physical condition.

Effect of cropping systems and bio-mulches on water holding capacity

Table 3 illustrates the effects of cropping systems and bio-mulch treatments on soil WHC. Cropping systems had no significant effect on soil WHC at 0-15 cm, 15-30 cm and 30-45 cm depths in both years (Table 3). Water holding capacity values decreased with increasing depth across all systems, with the lowest values consistently recorded under CS_3. In contrast, bio-mulch treatments significantly influenced WHC at all depths. The highest WHC was observed under the M_3 treatment (MSM + 5 t ha^{-1} paddy straw), with values up to 66.56 % (2017-18) at 0-15 cm and 68.58 % (2018-19) at 15-30 cm depth. The lowest WHC was found in the residue-removed plots (M_0), ranging from 50.42 to 55.66 %. Treatments M_2 (water hyacinth) and M_4(water hyacinth + paddy straw) also maintained relatively high WHC. A consistent decline in WHC with soil depth was evident across all treatments in the year 2017-18.

Effect of cropping systems and bio-mulches on infiltration rate

Fig. 1 illustrates effect of cropping system and bio-mulches on infiltration rate. Initial water infiltration was highest under CS_1 and lowest under CS_2 in both years, while CS_3 exhibited a higher basic (steady state) infiltration rate as time progressed. Cumulative infiltration was also highest in CS_3 (486.0 and 487.8 cm hr^{-1}), followed by CS_1 and lowest in CS_2. Bio-mulch treatments significantly enhanced infiltration. The highest basic and cumulative infiltration rates were recorded under M_3 (MSM + 5 t ha^{-1} paddy straw), reaching 517.2 and 513.6 cm hr^{1} in 2017-18 and 2018-19 respectively, followed by M_4 and M_2· The no-mulch treatment (M_0) consistently showed the lowest infiltration (466.8 and 467.4 cm hr^{-1}) (Fig. 1).

Soil microbial activity

Dehydrogenase activity (DHA)

Cropping systems had no significant effect on DHA at either soil depth. However, CS_3 consistently recorded the highest DHA at 0-15 cm, with values of 23.51 and 24.33 µg TPF hr^{-1} g^{-1} in 2017-18 and 2018-19 respectively (Table 4). In contrast, bio-mulch treatments significantly influenced DHA, particularly at the 0-15 cm depth. The M_3 treatment (MSM + 5 t ha^{-1} paddy straw) showed the highest DHA, with values of 25.32 and 26.70 µg TPF hr^{-1} g^{-1} in 2017 -18 and 2018-19. M_4 and M_2 were statistically comparable. At 15-30 cm, differences were non-significant, though M_3 showed a moderate increase over the no-mulch control. No significant interaction between cropping systems and mulch treatments was observed.

Soil microbial biomass carbon (SMBC)

Cropping systems had no significant effect on SMBC at either 0-15 cm or 15-30 cm soil depths. However, the highest SMBC was observed in CS_2 (186.33 µg g^{-1}) in 2017-18 and CS_3 (190.48 µg g^{-1}) in 2018-19 at 0-15 cm depth. A general decline in SMBC was noted with increasing soil depth. Bio-mulch treatments significantly affected SMBC at the 0-15 cm depth. The M_3 treatment (MSM + 5 t ha^{-1} paddy straw) recorded the highest SMBC-196.87 and 200.59 µg g^{-1} in 2017-18 and 2018-19 respectively-significantly surpassing the no-mulch treatment. At 15-30 cm, variations were non-significant, with the lowest SMBC observed under residue removal (Table 4).

Table 3. Effect of cropping systems and bio-mulches measures on soil bulk density (g cm^{-3}) and water holding capacity on Rabi crops

Treatments	Soil bulk density (g cm^{-3})				Water holding capacity (%)			
	2017-18		2018-19		2017-18		2018-19	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Cropping systems								
CS_1	1.27	1.30	1.26	1.30	61.27	59.55	57.83	63.06
CS_2	1.27	1.30	1.26	1.29	60.89	59.01	57.39	62.92
CS_3	1.27	1.30	1.27	1.29	61.66	59.98	59.11	63.32
SEm (±)	**0.01**	**0.01**	**0.01**	**0.01**	**1.19**	**0.82**	**1.51**	**0.73**
CD (*p*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Bio-mulches								
M_0	1.30	1.33	1.29	1.32	53.53	51.24	50.42	55.66
M_1	1.28	1.31	1.27	1.31	58.26	57.56	55.59	61.64
M_2	1.27	1.30	1.27	1.29	63.37	61.30	60.43	63.96
M_3	1.25	1.27	1.25	1.26	66.56	64.94	62.98	68.58
M_4	1.27	1.29	1.26	1.29	64.66	62.53	61.15	65.66
SEm (±)	**0.01**	**0.01**	**0.01**	**0.01**	**1.37**	**1.60**	**1.98**	**1.59**
CD (*p*=0.05)	**0.03**	**0.04**	**0.03**	**0.04**	**3.94**	**4.57**	**5.68**	**4.55**
Interaction	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

(Note: CS_1= maize-chickpea, CS_2 = maize-lentil, CS_3 = maize -lathyrus, M_0 = no mulch (residue removal), M_1 = *In-situ* maize stalk mulch (MSM), M_2 = MSM + water hyacinth (5 t ha^{-1}), M_3 = MSM + paddy straw (5 t ha^{-1}), M_4 = MSM + paddy straw (2.5 t ha^{-1}) + water hyacinth (2.5 t ha^{-1}), g cm^{-3} = gram per cubic centimeter, SEm = standard error of mean, CD = critical difference, NS = non-significant)

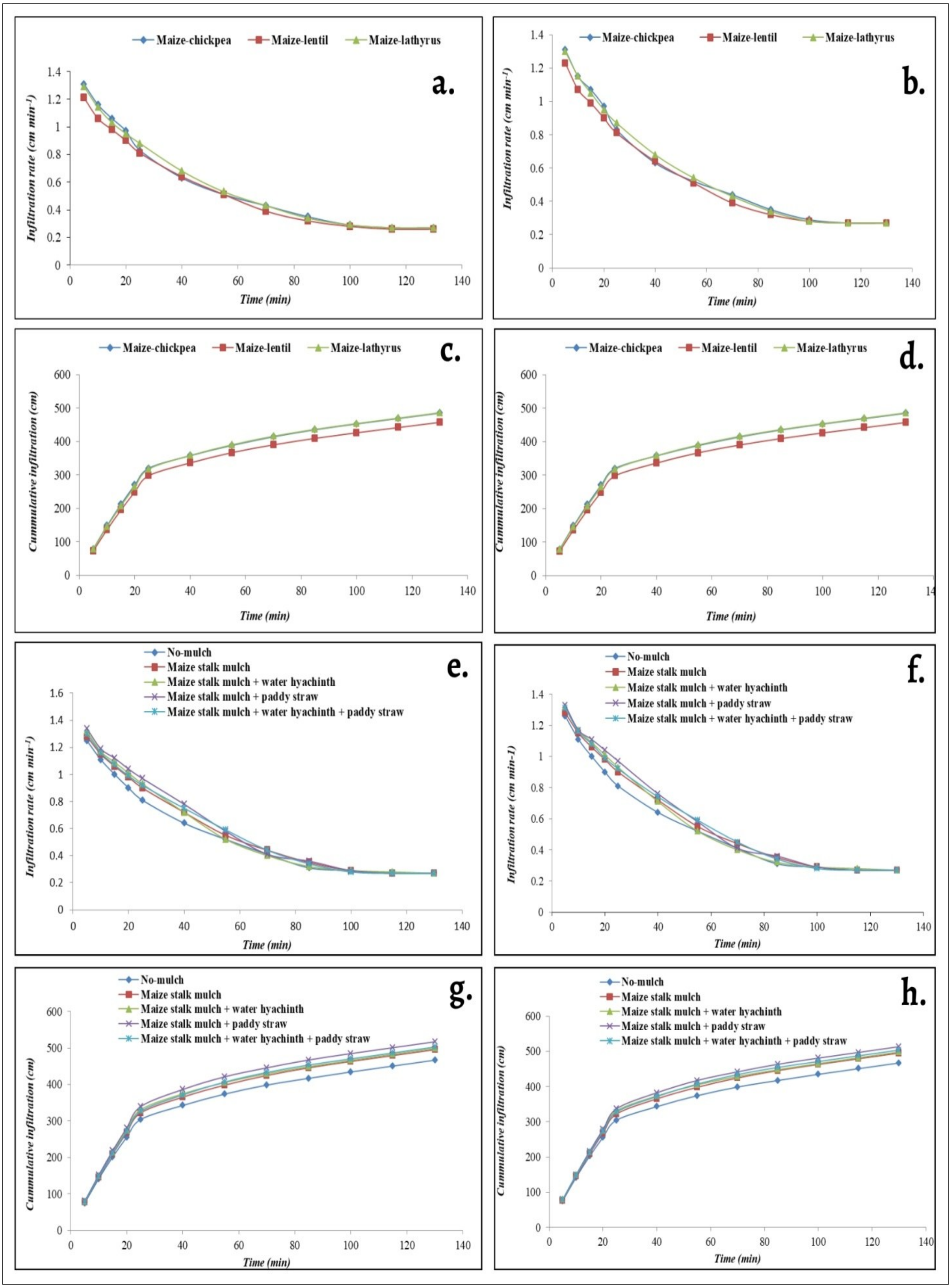

Fig. 1. Effect of cropping systems (a. 2017-18; b. 2018-19) and bio-mulches (e. 2017-18; f. 2018-19) on water infiltration rate (cm min^{-1}) and effect of cropping systems (c. 2017-18; d. 2018-19) and bio-mulches (g. 2017-18; h. 2018-19) on cumulative infiltration (cm) after the harvest of Rabi crops.

Table 4. Effect of cropping system and bio-mulches measures on soil dehydrogenase activity (µg TPF hr^{-1}g^{-1}) and soil microbial biomass carbon (µg g^{-1} soil) on Rabi crops

Treatments	**Soil dehydrogenase activity**				**Soil microbial biomass carbon**			
	2017-18		**2018-19**		**2017-18**		**2018-19**	
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**
Cropping systems								
CS_1	22.64	19.06	24.02	20.10	185.29	160.78	190.30	165.34
CS_2	22.72	19.13	24.18	20.19	186.33	162.34	189.21	166.19
CS_3	23.51	19.08	24.33	20.31	185.83	162.05	190.48	166.07
SEm (±)	**0.37**	**0.36**	**0.43**	**0.53**	**2.84**	**2.59**	**2.50**	**3.81**
CD (*p*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Bio-mulches								
M_0	20.37	18.54	21.68	19.52	168.80	155.83	172.85	158.91
M_1	21.35	18.89	22.59	19.96	177.29	159.25	180.77	163.12
M_2	23.28	19.13	24.60	20.17	192.18	160.02	198.08	166.62
M_3	25.32	19.59	26.70	21.03	196.87	169.45	200.59	173.12
M_4	24.47	19.30	25.31	20.32	193.95	164.06	197.70	167.57
SEm (±)	**0.36**	**0.44**	**0.50**	**0.67**	**3.91**	**4.21**	**3.58**	**3.47**
CD (*p*=0.05)	**1.04**	**NS**	**1.43**	**NS**	**11.21**	**NS**	**10.27**	**NS**
Interaction	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

(Note: CS_1= maize-chickpea, CS_2= maize-lentil, CS_3= maize -lathyrus, M_0 = no mulch (residue removal), M_1 = *In-situ* maize stalk mulch (MSM), M_2 = MSM + water hyacinth (5 t ha^{-1}), M_3 = MSM + paddy straw (5 t ha^{-1}), M_4 = MSM + paddy straw (2.5 t ha^{-1}) + water hyacinth (2.5 t ha^{-1}), g cm^{-3} = gram per cubic centimeter, SEm = standard error of mean, CD = critical difference, NS = non-significant)

Effect of bio-mulches on growth attributes

Bio-mulch treatments significantly enhanced biomass accumulation across chickpea, lentil and lathyrus. Biomass increased progressively with crop growth. The M_3treatment (MSM + 5 t ha^{-1} paddy straw) consistently produced the highest biomass in all crops, followed by M_4 and M_2. Residue removal resulted in the lowest biomass. At harvest, the highest biomass accumulation was recorded in lentil (357.17 g m^{-2} in 2017-18 and 367.00 g m^{-2} in 2018-19), lathyrus (464.75 and 462.33 g m^{-2}) and chickpea (396.83 and 393.92 g m^{-2}) under M_3. M_4 treatments showed the second-highest biomass across all crops and in both years (Table 5).

Effect of bio-mulches on WUE and water productivity

Bio-mulch treatments significantly improved WUE across all Rabi crops (Fig. 2). The M_3 treatment recorded the highest WUE, followed by M_4, in all crop varieties. Compared to no mulch, M_3 led to notable WUE increases in chickpea (101.54, 101.47 and 103.03 %), lentil (85, 81.36 and 85.71 %) and lathyrus (47, 133.33, 114.06 and 121.31 %) for the years 2017-18, 2018-19 and pooled data respectively. These improvements were mainly due to higher yields and better soil moisture retention. Lathyrus showed the highest WUE, particularly under M_3, attributed to its extended growth duration and higher evapotranspiration. The application of bio-mulch effectively conserved water by reducing evaporation and enhancing moisture availability for plant uptake, thereby increasing WUE and water productivity. Additionally, the combination of zero tillage and crop residue application improved soil physical properties, further contributing to enhanced yields and WUE (Fig. 3).

Discussion

Soil moisture content

The maize-lathyrus system retained higher soil moisture throughout the crop period, except at 90 DAS, where maize-lentil showed the highest levels. The better retention in maize-lathyrus is attributed to its ground-covering growth habit, which reduces evaporation losses (32). In contrast, maize-lentil had lower moisture due to less canopy coverage (17). Among mulching treatments, M_3 consistently maintained the highest soil moisture across all stages, followed by M_4, while control plots recorded the lowest. The use of maize stalks with paddy straw or water hyacinth in M_3 effectively minimized runoff and evaporation (33). Mulched plots preserved more moisture at all soil depths, especially in sub-surface layers (15-30 cm), due to reduced evaporation (34).

Water holding capacity

The maize-lathyrus system showed the highest water holding capacity, followed by maize-chickpea. This was influenced by lower bulk density, residue cover and reduced evaporation (35). Tillage absence may cause surface compaction, limiting infiltration (36). Mulching enhanced soil microbial activity and aggregation, improving structure and water retention (36).

Table 5. Effect of bio-mulches measures on dry matter accumulation (g m^{-2}) of chickpea, Lentil and Lathyrus at harvest

Treatments	**Chickpea**		**Lentil**		**Lathyrus**	
Bio-mulches	**2017-2018**	**2018-2019**	**2017-2018**	**2018-2019**	**2017-2018**	**2018-2019**
M_0	134.42	133.75	123.83	133.58	162.75	167.42
M_1	171.50	179.75	175.08	176.75	236.00	229.42
M_2	229.83	238.25	231.17	244.50	297.00	282.50
M_3	396.83	393.92	357.17	367.00	464.75	462.33
M_4	281.25	282.33	307.58	299.92	348.17	362.00
SEm (±)	**7.23**	**3.09**	**7.85**	**6.82**	**7.59**	**8.82**
CD (*p*=0.05)	**22.28**	**9.53**	**24.17**	**21.00**	**23.39**	**27.17**

(Note: M_0 = no mulch (residue removal), M_1 = *In-situ* maize stalk mulch (MSM), M_2 = MSM + water hyacinth (5 t ha^{-1}), M_3 = MSM + paddy straw (5 t ha^{-1}), M_4 = MSM + paddy straw (2.5 t ha^{-1}) + water hyacinth (2.5 t ha^{-1}), g cm^{-3} = gram per cubic centimeter, SEm = standard error of mean, CD = critical difference)

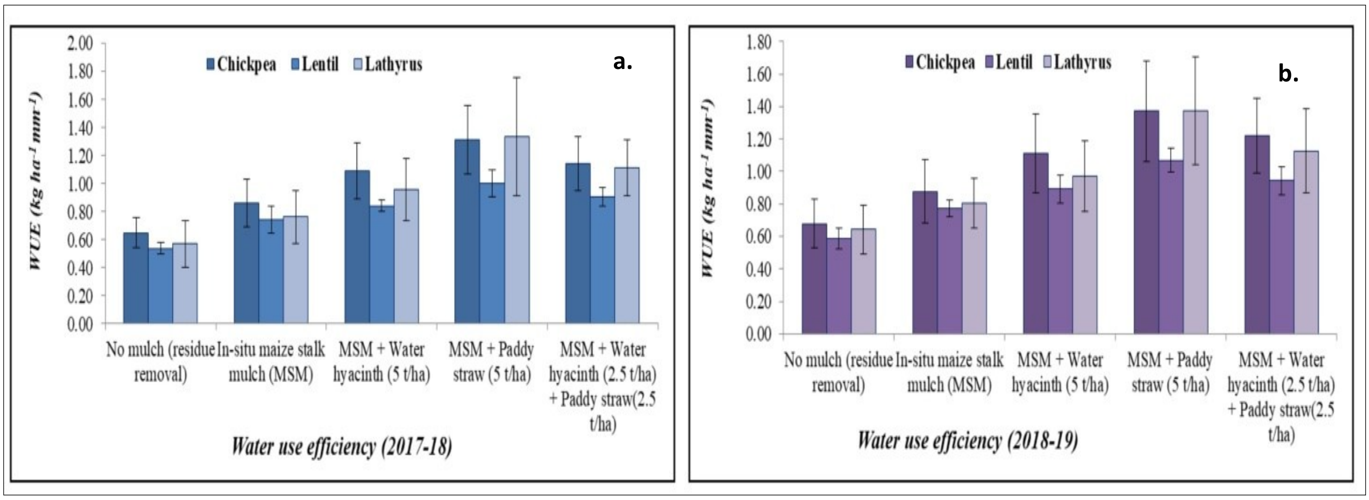

Fig. 2. Water use efficiency of Rabi crops under different bio-mulches measures; (a): 2017-18, (b): 2018-19.

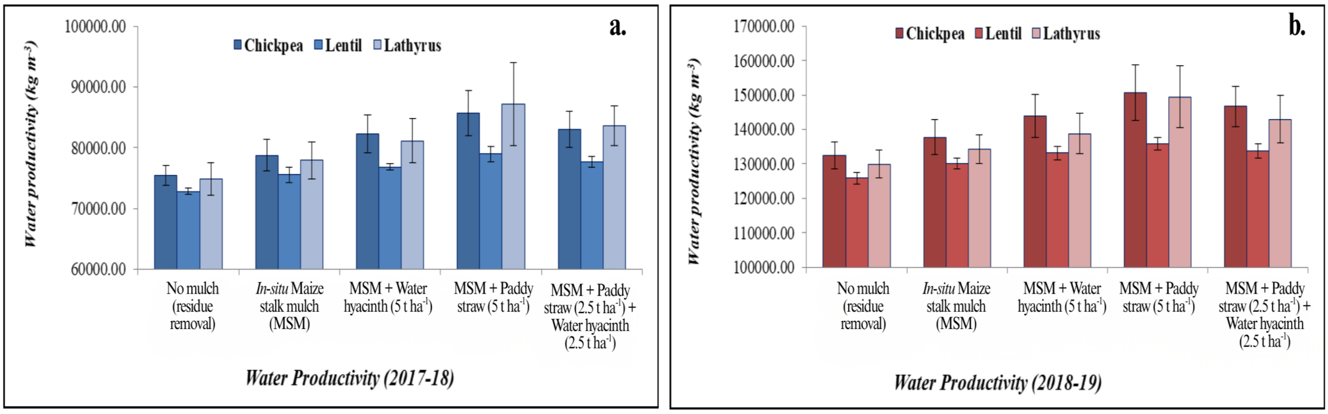

Fig. 3. Water productivity of different cropping systems affected by bio-mulches; (a): 2017-18, (b): 2018-19.

Infiltration

Infiltration rates were highest in the maize-lathyrus system and mulch-treated plots. M_3 treatment showed superior infiltration, likely due to improved soil structure from residue retention (23). Residues on the surface prevent sealing and promote water entry. Natural mulches further reduce runoff and improve infiltration (37). The lowest infiltration occurred in residue-removed plots can be due to the surface crusting and poor aggregation (37).

Dehydrogenase activity and soil microbial biomass carbon

Dehydrogenase activity (DHA) showed minimal variation across systems, likely due to legume inclusion enhancing microbial processes (38). However, M_3 had the highest DHA, followed by M_4, due to decomposition of high C:N ratio residues, improving nutrient availability and microbial energy sources (39). Soil microbial biomass carbon also remained similar across systems but was highest under M_3 (196.87 and 200.59 µg g^{-1} in 2017-18 and 2018-19), followed by M_4. This increase was due to zero tillage with residue retention, which supports microbial growth and carbon sequestration (24).

Crop growth attributes

Mulching significantly enhanced biomass and leaf area across all crops. M_3 plots showed the highest dry matter accumulation at harvest. Improved soil moisture, reduced compaction and nutrient release from decomposed biomass contributed to better growth under mulched conditions (40).

Conclusion

Retention of *in-situ* maize stalks along with paddy straw or water hyacinth mulch effectively conserved soil moisture, improved soil physico-chemical and biological properties and enhanced crop productivity. The highest water use efficiency was observed in the maize-lathyrus (CS_3) system under MSM + paddy straw (5 t ha^{-1}) mulch (M_3), followed by MSM + water hyacinth (2.5 t ha^{-1}) + paddy straw (2.5 t ha^{-1}) mulch (M_4). Maximum water productivity was recorded in the maize-chickpea (CS_1) system under M_3 mulch. Further, there are needs to study the root distribution and soil moisture extraction pattern of these legumes under different bio-mulching and climatic conditions.

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Authors' contributions

JKD and BKS did the conceptualization and methodology of the research. JKD and RD did data collection and data analysis. JKD, AD, AC and PD wrote the manuscript. AD, AC and PD did the reviewing and final editing of the manuscript. BKS, AD and AC did the final supervision of the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Bargali SS, Bargali K, Singh L, Ghosh L, Lakhera ML. *Acacia nilotica*-based traditional agroforestry system: effect on paddy crop and management. Curr Sci. 2009;25:581-7.
2. Bargali SS, Shahi C, Bargali K, Negi B, Khatri K. Energy and monetary efficiencies at different altitudinal agroecosystems in central Himalaya, India. Heliyon. 2022;8(11):e11500. https://doi.org/10.1016/j.heliyon.2022.e11500
3. Shahi C, Bargali SS, Bargali K, Vibhuti. Dry matter dynamics and CO_2 mitigation in the herb layer of Central Himalayan agroecosystems along an altitudinal gradient, India. Trop Ecol. 2023;64(1):180-92. https://doi.org/10.1007/s42965-022-00258-6
4. Negi B, Khatri K, Bargali SS, Bargali K. Invasive *Ageratina adenophora* (Asteraceae) in agroecosystems of Kumaun Himalaya, India: a threat to plant diversity and sustainable crop yield. Sustain. 2023;8(14):10748. https://doi.org/10.3390/su151410748
5. Negi B, Khatri K, Bargali SS, Bargali K, Fartyal A. Phenological behaviour of *Ageratina adenophora* compared with native herb species across varied habitats in the Kumaun Himalaya. Plant Ecol. 2025;226(3):237-49. https://doi.org/10.1007/s11258CFF024-01487-6
6. Gulati A, Juneja R. Indian agriculture towards 2030. Ministry of Agriculture and Farmers Welfare, Government of India; 2020. p. 1-27.
7. Chand R, Prasanna PL, Singh A. Farm size and productivity: understanding the strengths of smallholders and improving their livelihoods. Eco Pol Weekly. 2011;25:5-11.
8. Balkrishna A, Sharma G, Sharma N, Rawat N, Kumar A, Arya V. Transition of Indian agriculture from glorious past to challenging future: a serious concern. Indian J Ecol. 2022;49(3):977-86. https://doi.org/10.55362/IJE/2022/3625
9. Rahman S. Green revolution in India: environmental degradation and impact on livestock. Asian J Water Environ Pollut. 2015;12(1):75-80. https://doi.org/10.3233/AJW-2015-12_1_11
10. Kannan E. Trends in India's agricultural growth and its determinants. Asian J Agric Dev. 2011;8(2):79-99. https://doi.org/10.22004/ag.econ.199328
11. Kumar A, Tripathi HP, Yadav RA. Intensification and diversification in rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system for sustainability. Indian J Agro. 2012;57(4):319-22.
12. Prakash KN, Venkataramana MN. Growth of maize ecosystem in India and Karnataka vis-à-vis associated risk in production: an economic insight. Mysore J Agric Sci. 2023;57(2):264-72.
13. Imran A, Hakim S, Tariq M, Nawaz MS, Laraib I, Gulzar U, et al. Diazotrophs for lowering nitrogen pollution crises: looking deep into the roots. Front Microbiol. 2021;12:637815. https://doi.org/10.3389/fmicb.2021.637815
14. Das A, Devi TM, Babu S, Ansari M, Layek J, Bhowmick SN, et al. Cereal-legume cropping system in Indian Himalayan region for food and environmental sustainability. In: Meena R, Das A, Yadav G, Lal R, editors. Legumes for soil health and sustainable management. Singapore: Springer; 2018. p. 33-76. https://doi.org/10.1007/978-981-13-0253-4_2
15. Roy S, Hazra S. Monthly drought assessment and early warning for droughts in Purulia district of West Bengal. Indian Ground Water. 2020;XV:7-19.
16. Saha R, Ghosh PK, Das AD. Soil water dynamics and yield as influenced by residue and tillage management in maize (*Zea mays*)-mustard (*Brassica campestris*) cropping system. Indian J Agric Sci. 2009;79(5):340-5.
17. Dey JK, Saren BK, Debnath A, Gudade BA, Singh S, Kumar A, et al. Productivity and nutrient dynamics of legume in a maize-legume cropping system are influenced by biomulches under no-tillage system. Int J Plant Prod. 2022;16(3):531-45. https://doi.org/10.1007/s42106-022-00204-5
18. Bekele D. The effect of tillage on soil moisture conservation: a review. Int J Res Stud Agric Sci. 2020;6:30-41. https://doi.org/10.20431/2454-6224.0610004
19. Meena BP, Shirale AO, Dotaniya ML, Jha P, Meena AL, Biswas AK, et al. Conservation agriculture: a new paradigm for improving input use efficiency and crop productivity. In: Bisht J, Meena V, Mishra P, Pattanayak A, editors. Conservation agriculture. Singapore: Springer; 2016. p. 39-69. https://doi.org/10.1007/978-981-10-2558-7_2
20. Jalota SK, Khera R, Ghuman BS, editors. Method in soil physics. 1st ed. New Delhi: Narosa Publishing House; 1998.
21. Ghosh PK, Das A, Saha R, Kharkrang E, Tripathi AK, Munda GC, et al. Conservation agriculture towards achieving food security in Northeast India. Curr Sci. 2010;10:915-21.
22. Sarkar S, Paramanick M, Goswami SB. Soil temperature, water use and yield of yellow sarson (*Brassica napus* L. var. *glauca*) in relation to tillage intensity and mulch management under rainfed lowland ecosystem in eastern India. Soil Tillage Res. 2007;93(1):94-101. https://doi.org/10.1016/j.still.2006.03.015
23. Kumar R, Saurabh K, Mishra JS, Mondal S, Hans H, Sundaram PK, et al. Impact of conservation agriculture on soil properties and crop productivity under rice-fallow ecology in Eastern India. In: Jayaraman S, Dalal RC, Patra AK, Chaudhari SK, editors. Conservation agriculture: a sustainable approach for soil health and food security. Singapore: Springer; 2021. p. 165-93. https://doi.org/10.1007/978-981-16-0827-8_8
24. Dey JK, Saren BK, Duary B, Pramanik K. Performance of zero-till bio-mulching on different pulses under maize-legume sequence. Legume Res. 2023;46(2):176-80. https://doi.org/10.18805/LR-4395
25. Midya A, Saren BK, Dey JK, Maitra S, Praharaj S, Gaikwad DJ, et al. Crop establishment methods and integrated nutrient management improve: Part I. Crop performance, water productivity and profitability of rice (*Oryza sativa* L.) in the lower Indo-Gangetic plain, India. Agronomy. 2021;11(9):1860. https://doi.org/10.3390/agronomy11091860
26. Jalota SK, Singh KB, Chahal GB, Gupta RK, Chakraborty S, Sood A, et al. Integrated effect of transplanting date, cultivar and irrigation on yield, water saving and water productivity of rice (*Oryza sativa* L.) in Indian Punjab: field and simulation study. Agric Water Manag. 2009;96(7):1096-104. https://doi.org/10.1016/j.agwat.2009.02.005
27. Brookes PC, Joergensen RG. Microbial biomass measurements by fumigation-extraction. In: Bloem J, Hopkins DW, Benedetti A, editors. Methods for assessing soil quality. Cambridge: CABI Publishing; 2006. p. 77-83. https://doi.org/10.1079/9780851990989.0000
28. Li X, Chen Z. Soil microbial biomass C and N along a climatic transect in the Mongolian steppe. Biol Fertil Soils. 2004;39:344-51. https://doi.org/10.1007/s00374-004-0720-z
29. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. Soil Biol Biochem. 1987;19(6):703-7. https://doi.org/10.1016/0038-0717(87)90052-6
30. Casida Jr LE, Klein DA, Santoro T. Soil dehydrogenase activity. Soil Sci. 1964;98(6):371-6.
31. Gomez KA, Gomez AA, editors. Statistical procedures for Agricultural research. 2nd ed. Philippines: John Wiley & Sons; 1984.
32. Shi L, Dai C, Maruthaveeran S. Application of perennial sweet pea in soil and water conservation. Appl Sci. 2023;13(19):11075. https://doi.org/10.3390/app131911075

33. Blight G. Solar heating of the soil and evaporation from a soil surface. Geotechnique. 2009;59(4):355-63. https://doi.org/10.1680/geot.2009.59.4.355
34. Yusefi A, Firouzi FA, Aminzadeh M. The effects of shallow saline groundwater on evaporation, soil moisture and temperature distribution in the presence of straw mulch. Hydro Res. 2020;51(4):720-38. https://doi.org/10.2166/nh.2020.010
35. De Vita P, Di Paolo E, Fecondo G, Di Fonzo N, Pisante M. No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. Soil Tillage Res. 2007;92(1-2):69-78. https://doi.org/10.1016/j.still.2006.01.012
36. Liu Y, Gao M, Wu W, Tanveer SK, Wen X, Liao Y. The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China. Soil Tillage Res. 2013;130:7-12. https://doi.org/10.1016/j.still.2013.01.012
37. El-Beltagi HS, Basit A, Mohamed HI, Ali I, Ullah S, Kamel EA, et al. Mulching as a sustainable water and soil saving practice in agriculture: a review. Agronomy. 2022;12(8):1881. https://doi.org/10.3390/agronomy12081881
38. Duchene O, Vian JF, Celette F. Intercropping with legume for agroecological cropping systems: complementarity and facilitation processes and the importance of soil microorganisms: a review. Agric Ecosyst Environ. 2017;240:148-61. https://doi.org/10.1016/j.agee.2017.02.019
39. Pandey R, Bargali SS, Bargali K, Karki H, Chaturvedi RK. Dynamics of nitrogen mineralization and fine root decomposition in sub-tropical *Shorea robusta* Gaertner f. forests of Central Himalaya, India. Sci Total Environ. 2024;921:170896. https://doi.org/10.1016/j.scitotenv.2024.170896
40. Prem M, Ranjan P, Seth N, Patle GT. Mulching techniques to conserve the soil water and advance the crop production– a review. Curr World Environ. 2020;15:10-30. https://doi.org/10.12944/CWE.15.Special-Issue1.02

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