



Mulching and integrated nutrient management practices on enhancing soil microclimate and productivity in *rabi* maize (*Zea mays*) under eastern Indian conditions

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ABSTRACT

The performance of winter (*rabi*) maize (*Zea mays* L.) is mostly constrained by low soil moisture and nutrient availability. In such cases, integrated nutrient management and moisture conservation techniques have shown promising results. The present experiment was conducted during winter (*rabi*) season of 2020–21 and 2021–22 at the Instructional-cum-Research Farm, Assam Agricultural University, Jorhat, Assam to assess the effect of mulching and Integrated Nutrient Management practices (INM) for enhancing soil microclimate and productivity in *rabi* maize. The experiment was laid out in split-plot design (SPD) in sandy loam and acidic soils consisting of three mulching treatments, viz. No mulch (M_0), paddy straw mulch (M_1) and biodegradable film mulch (M_2) as main plots and sub-plot included eight INM treatments, viz. 100% recommended dose of fertiliser (RDF) (I_1); 100% RDF + water spray (I_2); 100% PK + 75% recommended dose of nitrogen (RDN) + 25% RDN through vermicompost (I_3); 100% PK + 75% RDN + 25% RDN through enriched compost (I_4); I_3 + 4% Vermiwash (I_5); I_4 +4% Vermiwash (I_6); I_3 + 4% Humic acid (I_7) and I_4 + 4% Humic acid (I_8); and maize hybrid DKC-9081 was used in this experiment. Among all the treatments, M_2 consistently performed well by enhancing soil temperature, soil moisture content, emergence count (%), LAI and yield attributing parameters like cob girth, cob length and grain yield increased by 16.57% compared to M_0 and M_1 . Among the INM treatments, integrating nitrogen with enriched compost and foliar spray of humic acid proved effective. Results revealed that the M_2 and nitrogen integrated with enriched compost and humic acid (I_8) which was applied through foliar spray resulted in higher growth and productivity presenting a sustainable pathway for improving yield potential under *rabi* maize.

Keywords: Integrated nutrient management, Mulching, *Rabi* maize, Soil moisture, Soil temperature

Agriculture today faces the critical challenge of sustaining productivity under increasing climatic uncertainties such as erratic rainfall, rising temperatures and extended dry spells. Among cereal crops, maize (*Zea mays* L.) is globally significant as a food, feed and industrial crop widely cultivated across India throughout the year. However, maintaining its productivity under variable climatic conditions remains a concern especially in rainfed regions. In Assam with an average annual rainfall of about 2000 mm and favourable temperatures, maize cultivation has considerable potential. Yet, the concentration of rainfall

during June–September and the prolonged dry period from November–March often lead to moisture stress and frequent *rabi* crop failures. Maintaining adequate soil moisture, temperature and nutrient availability during this period is essential for ensuring better establishment and yield. In such cases, mulching is an effective practice to mitigate soil moisture loss by evaporation and temperature fluctuations improving soil microclimate and crop performance (Kader *et al.* 2019, Javaid *et al.* 2022). Studies have shown that organic mulches such as paddy straw and biodegradable films enhance soil temperature regulation, water retention and leaf area development (Jain *et al.* 2017, Wang *et al.* 2019). However, region-specific studies on suitable mulch materials for maize under Northeast Indian conditions remain limited. Similarly, balanced nutrient management is crucial for sustaining soil fertility and productivity. Excessive use of chemical fertilisers has contributed to soil degradation and environmental pollution (Kumar *et al.* 2016, De Castro *et al.* 2021). Integrated nutrient

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management (INM) combining inorganic fertilisers with organic inputs such as vermicompost, enriched compost, humic acid or vermivash has been shown to enhance soil microclimate and crop performance (Ievinsh 2020, Li *et al.* 2022). Despite evidence supporting mulching and INM independently, their combined influence under Assam’s *rabi* conditions has not been well studied. Hence, the present study aimed to assess the interactive effects of different mulching materials and integrated nutrient management practices on soil microclimate, growth and productivity of maize in the *rabi* season of north-east India.

MATERIALS AND METHODS

Experimental site: The present experiment was conducted during winter (*rabi*) season of 2020–21 and 2021–22 at the Instructional-cum-Research Farm, Assam Agricultural University, Jorhat (26°84' N, 93°13' E; at an elevation of 86.7 m amsl), Assam. The experimental site was characterised by uniform soil fertility, good drainage and homogeneous soil texture. The soil was classified as sandy loam containing 60.04% fine sand, 21.98% silt and 17.98% clay in 2020 and 59.04% fine sand, 22.99% silt and 17.97% clay in 2021 determined by the Pipette Method (Piper 1966). The soil pH was 5.12 in 2020 and 5.16 in 2021 indicating an acidic reaction (Jackson 1973). Organic carbon content was 0.65% in 2020 and 0.69% in 2021 rated as medium. The available nitrogen content was 315.56 kg/ha and 326.25 kg/ha, respectively (medium), while available phosphorus (P₂O₅) was 34.89 kg/ha in 2020 and 33.89 kg/ha in 2021 (high) as per Bray’s method. The available potassium (K₂O) content was 201.45 kg/ha and 207.89 kg/ha in 2020 and 2021, respectively (medium, Flame Photometric method) (Jackson 1973). The meteorological data during the crop growth period are presented in Table 1.

Treatments and experimental design: The experiment was laid out in split-plot design (SPD) in sandy loam and acidic soils consisting of three mulching treatments, viz. No

mulch (M₀), paddy straw mulch (M₁) and biodegradable film mulch (M₂) as main plots and sub-plot included eight INM treatments, viz. 100% recommended dose of fertiliser (RDF) (I₁); 100% RDF + water spray (I₂); 100% PK + 75% recommended dose of nitrogen (RDN) + 25% RDN through vermicompost (I₃); 100% PK + 75% RDN + 25% RDN through enriched compost (I₄); I₃ + 4% Vermiwash (I₅); I₄+4% Vermiwash (I₆); I₃ + 4% Humic acid (I₇) and I₄ + 4% Humic acid (I₈) (Table 2).

The field was prepared using a tractor drawn disc plough followed by two harrowing to ensure a fine tilth. The sowing of DKC 9081 seed hybrid was carried out manually by dibbling method on 1 December 2020 and 26 November 2021 at a spacing of 60 cm × 25 cm using a seed rate of

Table 2 Treatment combinations and their description under different mulching and integrated nutrient management (INM) practices in *rabi* maize

Treatment combination	Treatment description
M ₀ I ₁	No Mulch + 100% RDF
M ₀ I ₂	No Mulch + 100% RDF + water spray
M ₀ I ₃	No Mulch + 100% PK + 75% RDN + 25% RDN through vermicompost
M ₀ I ₄	No Mulch + 100% PK + 75% RDN + 25% RDN through enriched compost
M ₀ I ₅	No Mulch + I ₃ + 4% Vermiwash
M ₀ I ₆	No Mulch + I ₄ + 4% Vermiwash
M ₀ I ₇	No Mulch + I ₃ + 4% Humic acid
M ₀ I ₈	No Mulch + I ₄ + 4% Humic acid
M ₁ I ₁	Paddy straw mulch + 100% RDF
M ₁ I ₂	Paddy straw mulch + 100% RDF + water spray
M ₁ I ₃	Paddy straw mulch + 100% PK+ 75% RDN+ 25% RDN through vermicompost
M ₁ I ₄	Paddy straw mulch + 100% PK+ 75% RDN+ 25% RDN through enriched compost
M ₁ I ₅	Paddy straw mulch + I ₃ + 4% Vermiwash
M ₁ I ₆	Paddy straw mulch + I ₄ +4% Vermiwash
M ₁ I ₇	Paddy straw mulch + I ₃ + 4% Humic acid
M ₁ I ₈	Paddy straw mulch + I ₄ + 4% Humic acid
M ₂ I ₁	Biodegradable film mulch + 100% RDF
M ₂ I ₂	Biodegradable film mulch + 100% RDF + water spray
M ₂ I ₃	Biodegradable film mulch + 100% PK + 75% RDN + 25% RDN through vermicompost
M ₂ I ₄	Biodegradable film mulch + 100% PK + 75% RDN + 25% RDN through enriched compost
M ₂ I ₅	Biodegradable film mulch + I ₃ + 4% Vermiwash
M ₂ I ₆	Biodegradable film mulch + I ₄ + 4% Vermiwash
M ₂ I ₇	Biodegradable film mulch + I ₃ + 4% Humic acid
M ₂ I ₈	Biodegradable film mulch + I ₄ + 4% Humic acid

RDF, Recommended dose of fertiliser; RDN, Recommended dose of nitrogen.

Table 1 Meteorological data during the crop growth periods

Parameter	2020–21	2021–22
Weekly mean maximum temperature (°C)	23.9–35.2	25.1–33.3
Weekly mean minimum temperature (°C)	8.2–19.6	8.2–19.9
Morning relative humidity (%)	82–99	97.16–99
Evening relative humidity (%)	56.2–63	40–71
Bright sunshine hours (BSSH) (h/day)	1.7–5.1	0.2–9.8
Maximum BSSH (h/day)	5.1 (18 th SMW: 16–23 Apr 2021)	9.8 (46 th SMW: 5–11 Nov 2021)
Minimum BSSH (h/day)	1.7 (10 th SMW: 8–14 Jan 2021)	0.2 (14 th SMW: 2–8 Apr 2022)
Total rainfall (mm)	120.8	336.4

22.5 kg/ha. For soil moisture conservation, two types of mulch treatments were evaluated. Paddy straw mulch was applied uniformly at 6 t/ha and 20 micron biodegradable plastic mulch was placed over the plots prior to sowing. The required doses of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) were supplied through urea, single super phosphate (SSP) and muriate of potash (MOP), respectively. Nutrient application through vermicompost (VC) and enriched compost (EC) was also done in accordance with treatment specifications. Foliar application of 4% vermiwash and humic acid was done at 30 days interval to assigned treatment plots using a knapsack sprayer. Observations on various growth and yield attributing characters were recorded periodically to evaluate the influence of different treatments. The observations of five plants were randomly selected and tagged from the net plot area. Samples were labeled properly and brought to the laboratory for further processing. Soil temperature was recorded using a soil thermometer at 30 days intervals at 5 cm depth at 8:00 AM and 2:00 PM from each treatment plot and averaged. Soil moisture content was recorded periodically at different crop growth stages (initial, 30, 60, 90 and 120 DAS) at a depth of 0–15 and 15–30 cm. Soil samples were collected randomly from each plot using a soil auger. The fresh weight of each sample was recorded in the laboratory after which the samples were oven-dried at $105 \pm 1^\circ C$ for 72 h until a constant weight was achieved. Soil moisture content was then calculated using the gravimetric method (Black 1965). Plant emergence was assessed at 10 days after sowing (DAS). The total number of emerged seedlings in each plot was counted and the emergence percentage was calculated. In addition to this, Leaf area index (LAI) was determined at 30 days intervals up to 120 DAS. The leaf area was estimated by multiplying the length and mean width of each leaf following the method described by Sestak *et al.* (1971). The ground area was calculated from the spacing of the plants and the LAI was calculated as follows:

$$LAI = \frac{\text{Total leaf area of the plant}}{\text{Ground area occupied by the plant}}$$

Five randomly selected cobs with husk from each plot were measured for length, and the mean value was expressed in centimetres. Similarly, cob girth was recorded as the average

circumference of five randomly selected dehusked cobs using sliding callipers. After harvest, the maize stalks were left in the field for one week, then cut at ground level, sun-dried, and weighed along with the cob pith. Grain yield from each plot was recorded, and the values were converted to q/ha for estimation of grain yield.

Statistical analysis: Data were statistically analysed by following the method of analysis of variance using split-plot design procedures as suggested by Panse and Sukhatme (1978). Critical difference was worked out at 5% level of probability wherever the treatment differences were found significant. Treatment differences that were non-significant were denoted as NS.

RESULTS AND DISCUSSION

Effect on soil microclimate studies: Mulching significantly influenced soil temperature at 5 cm depth and soil moisture content across different depths (0–15 and 15–30 cm) of crop stages in both the years (Fig. 1). At the initial stage, M_2 recorded the highest soil moisture content of 26.1 and 26.2% at 0–15 cm and 15–30 cm, which contributed to higher emergence count (Fig. 2). The high soil moisture content at initial and final stage was due to rainfall received in November (Initial stage) and March (120 DAS) months during both the years. Higher soil moisture content in deeper layers of 15–30 cm soil depth than 0–15 cm was likely due to capillary flux from below the root zone that contributed water to the root zone (Chen *et al.* 2020) and may be resulted from reduced evaporation and offers better

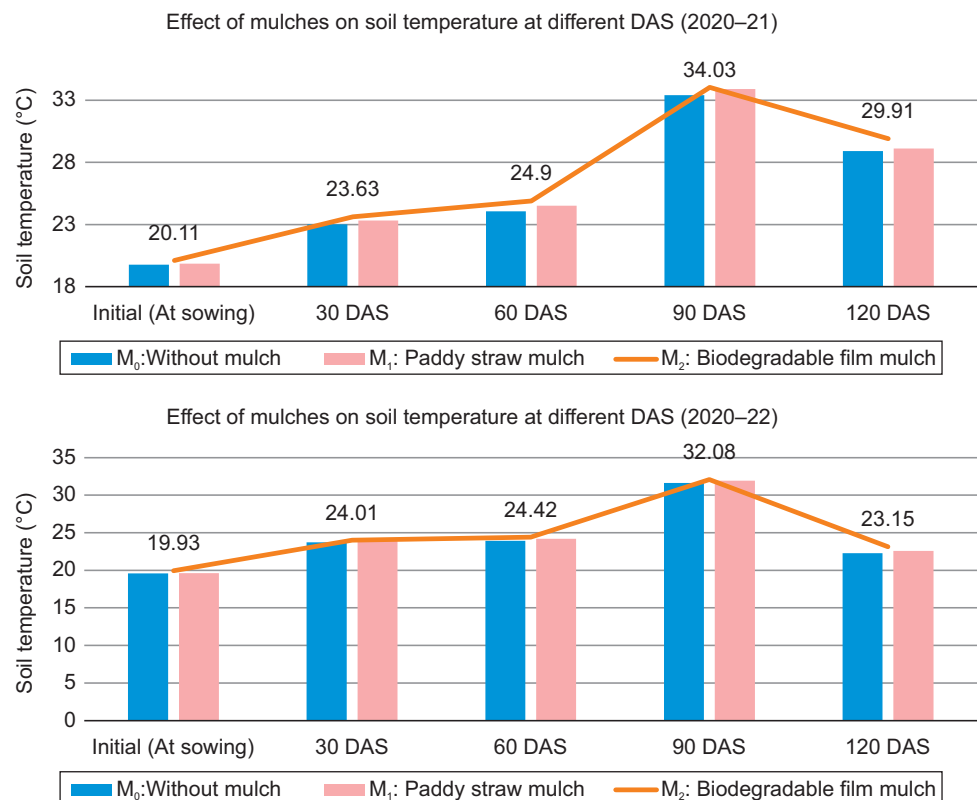


Fig. 1 Effect of mulches on soil temperature at different days after sowing (DAS) during both the years.

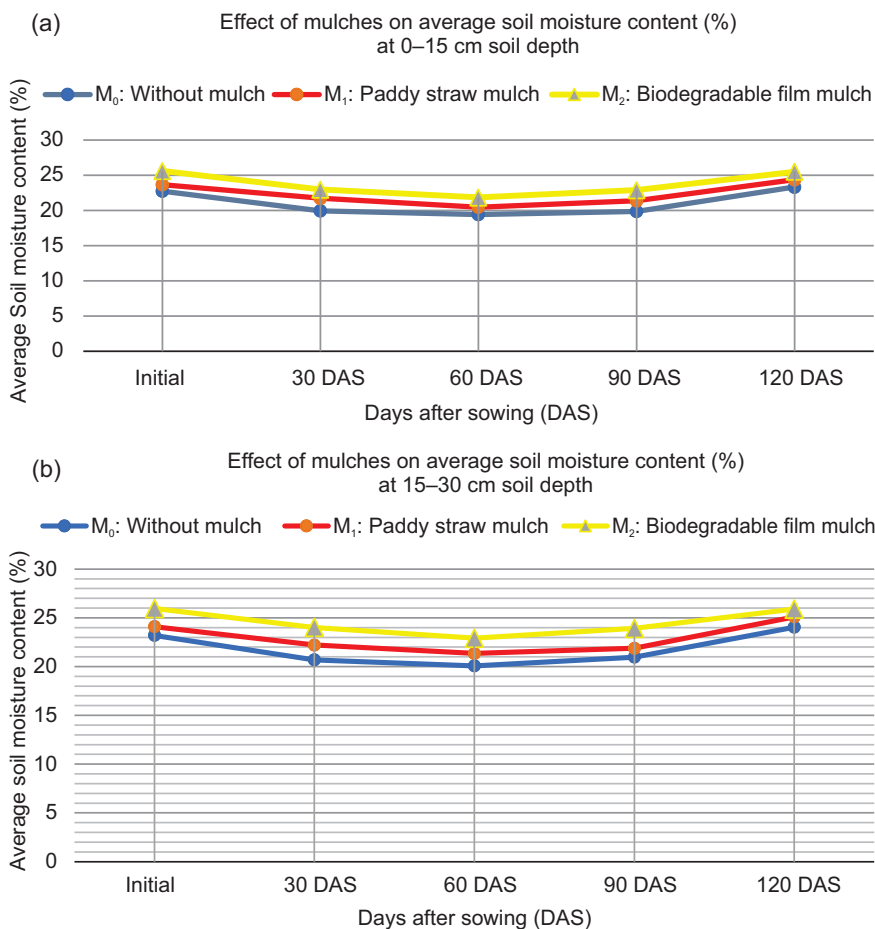


Fig. 2 Effect of mulching on soil moisture content (%) at different days after sowing at 0–15 cm and 15–30 cm soil depth during both the years.

insulation by biodegradable film mulch (Man *et al.* 2024). Generally, biodegradable film mulch followed by paddy straw mulch provided the highest moisture content. This aligned with findings of Zhang *et al.* (2020) and Fu *et al.* (2021) that plastic mulch improved moisture conservation and water use efficiency. Similarly, paddy straw mulch also protects the soil from extreme temperature fluctuations and helps retain soil moisture (Ma *et al.* 2024) as the protective layer reduces evaporation by shielding the soil from wind and direct sunlight (Tang *et al.* 2022). Additionally, soil temperature also affected significantly by M₂ treatment by recording 20.11°C and 19.93°C during both the years which was about 0.6–1.0°C higher than M₀, respectively. Warming effect continued and peaked at 90 DAS where M₂ registered 34.03 and 32.08°C temperature noticeably higher than M₀ (33.41°C and 31.62°C) even at 120 DAS. M₂ resulted in higher soil temperatures (29.91°C and 23.15°C) than M₀ (28.91°C and 22.28°C) in both years, respectively attributed to reduced surface evaporation and improved vapour movement from deeper layers (Gan *et al.* 2013) that resulted in better heat retention as supported by Ramakrishna *et al.* (2006). However, INM treatments had minimal (<0.1°C) and non-significant effects on soil temperature and moisture content indicating that mulching played a dominant role in modifying the soil microclimate.

Effect on crop growth: Over the two assessment years, the average highest emergence count (97.63% and 98.1%) was noted and LAI has increased progressively up to 90 DAS with a 55–60% rise from 30–90 DAS followed by a slight decline of 3–5% at 120 DAS with M₂ treatment that was at par with M₁ as shown for the most of the cases during both the years (Table 3). This may be attributed to enhanced soil moisture conservation and favourable soil temperature at initial stage of the crop creating a more favourable micro-environment for germination and early seedling establishment (Minh *et al.* 2023). Polythene mulch reduces soil erosion and slows rainwater infiltration during heavy rains (Prem *et al.* 2020) helping retain optimal moisture for better emergence and seedling growth. A slight increase in emergence across all treatments during the second year might be due to cumulative positive effect of mulch on soil properties and other reason supported by Singh *et al.* (2007) such as activation of the glycolysis process, lowering of inhibitory and dormancy inducing substances and mobilisation of auxins are other potential causes for better growth parameters. Similarly, significant results of LAI might be due to favourable microclimate (Soil temperature and soil moisture content), higher soil temperature at 90 DAS and higher CO₂ gas produced under polythene mulch, which could not escape easily and hence made it available for fixation in photosynthesis ultimately contributed to higher LAI (Jain *et al.* 2017). Among INM treatments, I₈ recorded the maximum LAI showing 19% improvement over control (I₁) which might be due to stimulation of physiological processes by humic acid as supported by Bul *et al.* (2013). The higher LAI at 90 DAS may be due to the increase in soil moisture content at initial crop stages, which led to higher storage of soil moisture and later helped in better root growth of maize contributing to higher growth and yield parameters (Chen *et al.* 2015).

Effect on crop yield and yield attributes: Mulching and integrated nutrient management (INM) practices significantly influenced yield parameters (Cob girth, cob length, grain yield) (Table 3). Among mulching treatments M₂ recorded the highest performance with average cob girth, cob length and grain yield increase of 36.60%, 11.90%, and 16.57%, respectively over the M₀ and 14.22% in cob girth, 3.62% in cob length and 11.47% in grain yield increase over M₁. The superior performance under M₂ can be attributed to better soil moisture conservation and thermal regulation

Table 3 Influence of mulching and integrated nutrient management practices on plant growth, average yield and yield attributing characters

Treatments	Leaf Area Index (LAI)				Yield attributing parameters			
	30 DAS	60 DAS	90 DAS	120 DAS	Cob length (cm)	Cob girth (cm)	Stover yield (q/ha)	Grain yield (q/ha)
Main plot treatments: Mulching								
M ₀	1.61	2.61	4.54	4.46	18.30	11.01	103.97	65.07
M ₁	2.36	3.31	5.47	5.37	21.89	11.89	108.45	68.03
M ₂	2.86	3.40	6.02	5.83	25.01	12.32	112.67	75.83
SEM±	0.03	0.04	0.21	0.11	0.37	0.15	2.01	0.95
CD (p=0.05)	0.11	0.16	0.83	0.44	1.45	0.58	NS	3.73
Sub-plot treatments: INM								
I ₁	2.07	2.91	4.62	4.49	20.21	10.72	105.74	65.64
I ₂	2.07	2.89	4.78	4.71	20.75	11.22	107.73	66.53
I ₃	2.20	2.88	4.91	4.90	21.38	11.50	108.03	67.37
I ₄	2.25	3.09	5.40	5.27	21.70	11.37	108.00	67.37
I ₅	2.29	3.11	5.48	5.34	21.86	11.83	109.42	70.59
I ₆	2.39	3.28	5.79	5.62	22.43	12.40	108.54	73.15
I ₇	2.39	3.28	5.80	5.64	22.36	12.32	107.32	71.77
I ₈	2.54	3.43	5.99	5.79	23.18	12.56	112.13	74.73
SEM±	0.04	0.09	0.18	0.17	0.51	0.31	2.41	1.14
CD (p=0.05)	0.13	0.25	0.50	0.48	1.45	0.89	NS	3.26
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

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

that improved soil microclimatic conditions contributing to higher plant growth attributes (Emergence count and LAI) and yield parameters (Cob girth and cob length). These results aligned with the findings of Verma *et al.* (2019) and Meena *et al.* (2020). In the sub-plot treatments, I₈ proved most effective in achieving maximum cob girth, cob length and grain yield which were 14.69%, 17.17% and 13.84% higher, respectively compared to I₁. Other INM treatments like I₆ and I₇ also showed notable grain yield improvements of 11.43% and 9.34%, respectively. The positive response under I₈ might be the synergistic effect of organic amendments and humic acid (Jat *et al.* 2021). Treatments incorporating organic sources such as vermicompost, enriched compost, vermiwash and humic acid consistently showed higher biomass accumulation (Kumar *et al.* 2018). Although stover yield was numerically highest under M₂ (112.67 q/ha) and I₈ (112.13 q/ha), differences among mulching and INM treatments were statistically non-significant, which is consistent with Singh *et al.* (2020).

The study showed that both mulching and integrated nutrient management significantly improved soil microclimate, growth and yield parameters of *rabi* maize. M₂ showed the highest cob length, cob girth and grain yield increase over M₀ while M₁ also performed better than M₀. The soil temperature and soil moisture content also recorded significant values under the treatment M₂. Among INM treatments, the treatment I₈ recorded the highest cob

length, cob girth and grain yield with an 13.84% increase over I₁. The results suggested that using biodegradable mulch with organic-enriched nutrient sources (Enriched compost and humic acid) is a promising and sustainable approach to increase the *rabi* maize productivity.

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