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Organic Mulching in Conjunction with Potassium Fertilization Effectively Regulates Soil Temperature and Enhances the Emergence, Physiological Development and Yield Performance of Late Sown Winter Maize (*Zea mays* L.)

H. Mandi[1], S. Bandyopadhyay[1], A. Rai[2], K. Nandi[1], H. S. Mallik[1], S. Dutta[1], S. Rai[1] and T. Paul[1]

[1]Dept. of Agronomy, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal (736 165), India
[2]Regional Research Station (Hill Zone), Uttar Banga Krishi Viswavidyalaya, Kalimpong, West Bengal (734 301), India

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Corresponding tarun.bckv@gmail.com

0000-0002-0102-5002

ABSTRACT

The experiment was conducted during the *rabi* season of 2017–18 and 2018–19 to study the 'effect of organic mulch and potassium fertilization on crop emergence, development, and productivity of maize under low temperature conditions' at the Instructional farm of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari, Cooch Behar, West Bengal, India. Low soil temperatures during winter significantly hinder seed germination, early crop establishment, and overall productivity of maize, while imbalanced potassium fertilization further disrupts its physiological functions. A total of 20 treatment combinations were incorporated using a split-plot design, replicated thrice. The main plots featured four organic mulches: straw mulch @10 t ha^{-1}; weed mulch @10 t ha^{-1}; vermicompost-mulch @ 5 t ha^{-1} and control, while sub-plots included six potassium levels: 0; 20; 40; 60; 80, and 100 kg ha^{-1}. Results revealed that soil temperature, crop emergence, physiological development and productivity significantly improved with the mulching practices and potassium fertilization. Organic mulches significantly improved soil temperature and emergence rate, which varied from 11.57–15.63% at 10 DAS and 10.35–13.39% at 15 DAS over the control. Grain yield increment varied from 23.16 to 33.17% with organic mulch compared to the control. With respect to potassium fertilization, grain and stover yields increased progressively with increasing potassium doses. Grain yield increment observed was 5.59–23.87% over the control. The highest net return and B:C were achieved under weed mulch, while potassium @ 100 kg ha^{-1} showed the highest values. Weed mulch combined with higher potassium fertilization would be the viable option for achieving maximum productivity and economic profitability of maize for the farming community of the Eastern Sub-Himalayan region.

KEYWORDS: Low temperature stress, maize, mulches, potassium fertilization, yield

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1. INTRODUCTION

Maize (*Zea mays* L.) is predominantly a rainy (*kharif*) season crop, but in recent years, winter (*rabi*) maize has gained significant importance due to higher productivity, less disease and pest infestation, as well as efficient crop management. The Terai region of the Eastern Sub-Himalayan plain is characterized by low temperatures during the winter season, especially from December to January. Farmers of this region most of the time cannot grow the crop before mid-December, particularly when maize is taken after the harvesting of rice. In this situation, the soil temperature becomes very low in the last week of December to the first fortnight of January. Crop when sown, suffers severely from low temperature for germination, emergence, and early crop stands, as soil temperature goes down to ≤100c °C (base temperature). Poor and erratic germination at suboptimal temperatures is the main hindrance to early sowing of maize (Ahmad et al., 2015). Seed germination, a problem that often occurs in the initial stages of maize growth and competition of seed sown with existing weeds in the soil (Hanim et al., 2010). Organic mulching (vermicompost, weed, straw mulch, etc.) regulates soil temperature to some extent as well, which triggers germination and emergence of the crop. It greatly retards the loss of moisture from the soil (Kumar et al., 2024; Ainapur et al., 2023). As a result, a higher and uniform soil moisture regime is sustained, reducing the irrigation frequency. A recent study showed that globally about 60% of cereal-growing soils are deficient in available potassium, compromising photosynthesis, biomass accumulation, and grain yield (Thenveettil et al., 2024). Potassium nutrition plays a pivotal role in maize growth and grain formation (Gnanasundari et al., 2018; Thenveettil et al., 2024) as K is involved in 60 enzymes (Sardans and Peñuelas et al., 2021) and water regulation in plants. Physiological experiments further confirmed that potassium-deficient maize plants suffer reductions of 30-85% in leaf area growth and photosynthetic rate, depending on severity (Thenveettil et al., 2024). Potassium is considered an important mineral nutrient for plants after nitrogen (White and Karley, 2010), which needs to be applied in sufficient enough to produce healthy and productive crops. Potassium is the primary major nutrient, which is a non-structural component of the plant body (Zhu et al., 2025; Sardans and Peñuelas et al., 2021). It increases plant tolerance to low temperature/frost and heat injuries, drought and enhances the resistance to diseases of different pest incidence and keeps anion balance in plants (Wang et al., 2013). The optimum amount of potassium in the soil in case of water scarcity comparatively enhances deposition of total dry matter in the plants compared to soil with less potassium regimes (Rosenstock et al., 2016). A soil deficient in potassium results in reduced plant photosynthesis (Wang et al., 2015; Chen et al., 2018; Luo et al., 2025), which is the main cause of low yield of maize. Split application of potassium enhances the physiological functions of plants (Wang et al., 2025; Sharma and Singh, 2021), rather than increasing its efficiency. Therefore, organic mulch and potassium may have a positive role in regulating low-temperature stress conditions. Hence, the present study was conducted to study the effect of organic mulch and potassium fertilization on crop emergence, development and productivity of maize under low temperature conditions. The study aimed to investigate whether mulching would regulate the soil temperature and its positive effect on crop emergence, establishment and productivity, while potassium fertilization would improve the physiological function of maize to increase productivity.

2. MATERIALS AND METHODS

2.1. Experimental site

A consecutive two-year field investigation was carried out during the winter (*rabi*) seasons of 2017–18 and 2018–19 to study the 'effect of organic mulch and potassium fertilization on crop emergence, development and productivity of maize under low temperature conditions' at the Instructional farm of Uttar Banga Krishi Viswavidyalaya (UBKV), Pundibari, Cooch Behar, West Bengal, India. Geographically, the site is located within the Eastern Sub-Himalayan plains, situated at 26°36'2'' N latitude and 88°47'44'' E longitude, with an elevation of 48 meters above mean sea level.

2.2. Edaphic factor

The soil was categorized as inceptisol and entisol, having sandy loam in the textural class. The soil was acidic in pH and had a low fertility status. The initial soil analysis showed that the pH value was 5.72; low in organic carbon (0.66%); available nitrogen (167 kg ha^{-1}); available phosphorus (21.0 kg ha^{-1}), and available potassium (187 kg ha^{-1}).

2.3. Experimental design and treatment details

The field experiment was meticulously structured using a split-plot design, incorporating a total of 20 treatment combinations to explore the interactive effects of mulch practices and potassium fertilization. The main plots featured four distinct mulch practices: M_1=Straw mulch @ 10 t ha^{-1}; M_2=Weed mulch @ 10 t ha^{-1}; M_3=Vermicompost-mulch @ 5 t ha^{-1} and M_4=No mulch (control); while, the sub-plots included six potassium levels: S_1=0 kg ha^{-1} (Control); S_2=20 kg ha$_{-1}$; S_3=40 kg ha^{-1}; S_4=60 kg ha^{-1}; (30 kg at basal+15 kg at 40 DAS+15 kg at 75DAS); S_5=80 kg ha^{-1} (40 kg at basal+20 kg at 40 DAS+20 kg at 75DAS) and S_6=100 kg ha^{-1} (50 kg at basal+25 kg at 40 DAS+25 kg at 75 DAS), all assigned randomly and replicated three times to ensure statistical precision.

2.4. Agricultural operation

Mulching materials were placed on the surface of the seedbed after the sowing operation as per treatments. Nitrogen and phosphorus were applied @ 140:70kg ha^{-1}. Potassium was applied as per the treatment taken under study. Fertilizers were applied in the form of urea (46% N), DAP (46% P_2O_5), and MOP (60% K_2O). The high-yielding maize hybrid NMH 1247 was sown on 27th December, 2017 and 27th December, 2018, and harvested on 2nd May, 2018 and 3rd May, 2019, respectively. Harvesting of cobs was performed when more than 80% of the cob color turned yellow, with grain moisture content around 20%.

2.5. Observation recorded

Biometric observations were recorded as per treatments taken under study, whereas at harvest, yield attributes were recorded plot-wise to ensure accuracy in yield assessment. The weather parameters recorded during the study are presented in Figure 1.

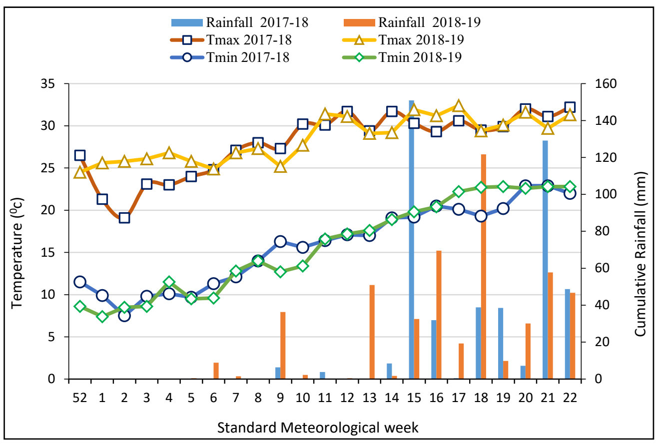

Figure 1: Weekly mean temperature and cumulative rainfall during crop seasons

2.6. Statistical analysis

The data gathered from the field and laboratory were analyzed through standard statistical procedures using the F-test. Different levels of main plot and sub-plot treatments means were compared using the least significant difference (LSD) test.

3. RESULTS AND DISCUSSION

3.1. Regulation of soil temperature

Regulation of soil temperature was recorded at 1,3,5,7,10,12, and 15 days after sowing (DAS). Organic mulching had a significant effect on soil temperature, while potassium fertilization had no significant effect (Table 1). Regulation of soil temperature was enhanced from 7–15 DAS compared to the initial DAS. Analyzed results showed that soil temperature significantly increased at both soil depths (i.e., from 0–5 cm and 6–10 cm depth) with the application of organic mulching.

Organic mulches (straw, weed biomass, and vermicompost) physically altered the soil-atmosphere energy exchange in the seedbed (Rossi et al., 2024), which explained the regulation of soil temperature, strongest from 7–15 DAS, and evident at both 0–5 and 6–10 cm. A surface mulch layer reduced direct wind exposure and evaporative cooling, so the topsoil stayed wetter; wetter soil had higher thermal conductivity and heat capacity, allowing more daytime heat to be conducted downward and less lost at night, raising the sub-surface mean temperature while damping extremes. Darker, moist mulches (e.g., weed mulch and vermicompost at the rates used) also had lower albedo and absorbed more short-wave radiation, further increasing heat transfer into the upper 10 cm. By around 7 days after sowing (DAS), the mulch layer settled, surface moisture became steady, and the early changes in the seedbed reduced. After this, the mulch's insulating and heat-regulating effects worked more consistently, which is why regulation was clearer between 7 and 15 DAS than in the first few days. In contrast, potassium fertilizer affected plant physiological factors (Wang et al., 2013), not the soil's heat balance. During the first 0–15 days after sowing, when the canopy had not developed properly and potassium had not influenced transpiration or ground cover, it did not affect soil temperature. Therefore, potassium showed no significant effect on soil temperature in this period.

3.2. Growth attribute

Crop emergence rate was recorded at 5, 10, and 15 DAS, and it was observed that mulching treatments had a significant effect on emergence rate, showing 11.57–15.63% higher at 10 DAS and 10.35–13.39% higher at 15 DAS compared to no mulch (Table 2). Vermicompost mulch recorded the highest value, followed by weed and straw mulch treatments, while potassium did not affect the emergence rate. Results showed that plant height (cm) and dry matter accumulation (g m^{-2}) increased progressively with the advancement of crop growth stages from 30 to 90 DAS (Figure 2). Among the mulch practices, vermicompost mulch (M_3) consistently recorded the maximum values at all stages of observation, followed by straw mulch (M_1) and weed mulch (M_2), whereas the control (M4) registered the lowest values. Similarly, potassium fertilization exerted a significant effect on both attributes. The maximum values were obtained in S_6 (100 kg ha^{-1}). Intermediate doses of potassium (20, 40, 60 and 80 kg ha^{-1}) were recorded in a gradual ascending order between the two extremes. Vermicompost-mulch (M_3) consistently recorded the highest LAI at all growth

Table 1: Effect of organic mulch and potassium fertilization on the regulation of soil temperature (mean of two years)

Treatment	Regulation of soil temperature (°C)													
	1 DAS		3 DAS		5 DAS		7 DAS		10 DAS		12 DAS		15 DAS	
	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth	0-5 cm depth	6-10 cm depth
Main plot (Organic mulches)														
M_1	14.46	15.92	14.86	15.67	13.12	15.07	14.98	15.98	13.38	15.30	13.97	16.33	15.54	16.93
M_2	14.40	15.64	14.19	15.36	13.09	15.00	14.86	15.49	13.20	15.33	13.89	15.96	15.23	16.88
M_3	14.89	16.27	14.89	15.78	13.66	15.30	15.38	16.49	13.91	15.48	14.29	16.54	15.94	17.63
M_4	13.51	14.58	12.38	13.35	12.46	13.32	14.27	15.08	12.61	13.71	13.31	14.52	14.48	15.55
LSD (*p*=0.05)	0.46	0.26	0.34	0.33	0.29	0.14	0.24	0.15	0.09	0.13	0.11	0.22	0.14	0.27
Sub-plot (Potassium fertilization)														
S_1	14.17	15.39	13.98	14.95	13.00	14.58	14.73	15.68	13.19	14.86	13.80	15.68	15.19	16.62
S_2	14.35	15.64	14.13	15.01	13.16	14.63	14.88	15.75	13.21	14.95	13.88	15.83	15.29	16.69
S_3	14.43	15.44	14.13	15.06	13.01	14.71	14.88	15.72	13.29	14.90	13.81	15.84	15.27	16.76
S_4	14.31	15.73	14.13	14.91	13.03	14.71	14.94	15.69	13.35	15.00	13.93	15.79	15.33	16.87
S_5	14.38	15.68	14.13	15.16	13.05	14.68	14.91	15.84	13.33	15.03	13.90	15.88	15.38	16.83
S_6	14.26	15.76	13.98	15.16	13.23	14.73	14.90	15.88	13.28	14.99	13.89	15.99	15.36	16.72
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
M×S (Organic mulches×Potassium fertilization)														
LSD (*p*=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: non-significant

stages, followed by straw mulch (M_1) and weed mulch (M_2), while control (M_4) showed the lowest values. Increasing potassium levels from S_1 (0 kg ha^{-1}) to S_6 (100 kg ha^{-1}) led to a progressive rise in this parameter. Treatments with split potassium application (S_4-S_6) outperformed those with only basal application (S_1-S_3). The interaction effect was non-significant, but M_3 with S_6 showed overall superiority at all growth stages. Both mulch and potassium application independently influenced plant growth without a synergistic response.

Improvement in soil temperature with mulching became ideal for crop emergence, which was attributed to continuous cell division and elongation, leading to vegetative growth with crop age. Vermicompost mulch practices had not only regulated soil temperature but also enhanced soil moisture as well as nutrient availability (Hasan et al., 2018), which favored better root growth and nutrient uptake (Azarmi et al., 2008). Straw and weed mulch also conserved soil moisture and reduced temperature fluctuations. Potassium plays a vital role in photosynthesis (Tewari et al., 2021; Ahmed et al., 2023; Adams et al., 2018; Borrelli et al., 2018), enzyme activation (Huai et al., 2022; Kumar et al., 2020), and water regulation, thereby promoting cell expansion and stem elongation (Komosa and Szewczuk, 2002). Hence, increased potassium doses progressively enhanced plant height, dry matter accumulation and leaf area index with maximum growth (Tewari et al., 2021) at 100 kg K_2O ha^{-1}. Split application (S_4-S_6) of potassium ensured efficient utilization by the plant, availability during critical growth stages, and improved canopy development.

3.3. Yield attributes

Yield attributes varied significantly with mulch practices and potassium fertilization (Figure 3). Among the mulch practices, vermicompost-mulch (M_3) recorded the highest number of cobs plant^{-1} and number of grains cob^{-1}, followed by straw (M_1) and weed mulch (M_2), while the control (M_4) registered the lowest value. Similarly, increasing potassium doses from S_1 (0 kg ha^{-1}) to S_6 (100 kg ha^{-1}) resulted in a progressive increase in the number of cobs plant^{-1}, with the maximum values under S_6. Mulch practices did not

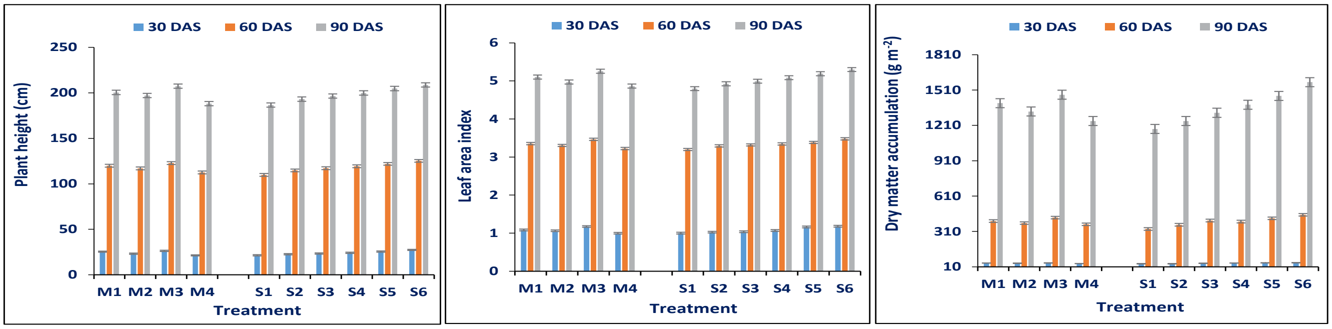

Figure 2: Effect of organic mulch and potassium fertilization on growth attributes of maize (mean of two years)

significantly affect the test weight of grains, as values remained statistically similar across treatments. However, potassium fertilization showed a gradual increase in test weight with increasing levels from S_1 to S_6. The interaction effect of mulch practices and potassium levels was found to be non-significant as these influenced independently.

Mulch practices increased plant growth, which was attributed to an increase in cobs plant^{-1} and grains cob^{-1}. Mulching (vermicompost mulch) also improved soil moisture in the crop root zone (Demo and Asefa Bogale, 2024), better soil aeration and availability of nutrients from gradual decomposition, which collectively supported better cob initiation and grain setting. It also stimulated microbial activity (Singh et al., 2008; Archana and Anubha, 2011; Amooaghaie and Golmohammadi, 2017), leading to greater nutrient mineralization and uptake. The increase in cobs plant^{-1} and number of grains cob^{-1} at higher potassium doses with split application occurred due to enzyme activation attributed to higher photosynthesis (Johnson et al., 2022), assimilate transport, protein synthesis (Hasanuzzaman et al., 2018), and regulation of water balance in the plant system. Enhanced photosynthesis and assimilate transport (Liesche, 2016) ensured better ear initiation and kernel development. The test weight, which depended on grain size, was a genetically controlled factor, although slightly affected by the management practices. In this study, mulch practices as well as potassium fertilization slightly increased this factor that was recorded due to assimilate translocation to developing grains (Liesche, 2016).

Table 2: Effect of organic mulch and potassium fertilization on crop emergence rate of maize (mean of two years)

Treatment	Crop emergence rate (%)		
	5 DAS	10 DAS	15 DAS
Main plot (Organic mulches)			
M_1	2.25	70.24	84.52
M_2	2.78	68.65	83.07
M_3	3.04	71.96	85.98
M_4	0.00	60.71	74.47
LSD (p=0.05)	2.00	7.27	6.56
Sub-plot (Potassium fertilization)			
S_1	1.59	65.28	79.17
S_2	2.38	67.06	81.94
S_3	1.59	67.26	81.75
S_4	2.38	68.45	82.34
S_5	2.38	69.44	83.53
S_6	1.79	69.84	83.33
LSD (p=0.05)	NS	NS	NS
M×S (Organic mulches×Potassium fertilization)			
LSD (p=0.05)	NS	13.02	NS

NS: non-significant

3.4. *Yields and harvest index*

Mulch practices and potassium levels significantly influenced grain and stover yield (Table 3). Organic mulch showed an increment of 23.16–33.17% in grain yield and 18.22–27.43% stover yield compared to the control. Among the mulch practices, vermicompost-mulch (M_3) recorded the highest grain and stover yield (8.44 t ha^{-1} and 11.19 t ha^{-1}, respectively). With respect to potassium fertilization, grain and stover yields increased progressively with increasing potassium doses from S_1 to S_6. The yield increment was observed 5.59-23.87% in grain and 7.63–27.71% in straw over the control. The highest grain and stover yields were recorded under S_6 (8.21 t ha^{-1} and 11.55 t ha^{-1}, respectively). The lowest yields were obtained under control. The harvest index (HI) was a non-significant variation across mulch treatments and different potassium levels. The interaction effect between mulch practices and potassium levels was found to be non-significant. Both mulch and potassium application independently influenced grain and stover yield without a synergistic response.

The higher grain and stover yields under mulch practices, especially with vermicompost mulch, were mainly due to improved crop growth, such as dry matter accumulation and leaf expansion, leading to higher photosynthate accumulation in the sink and grain formation. Organic

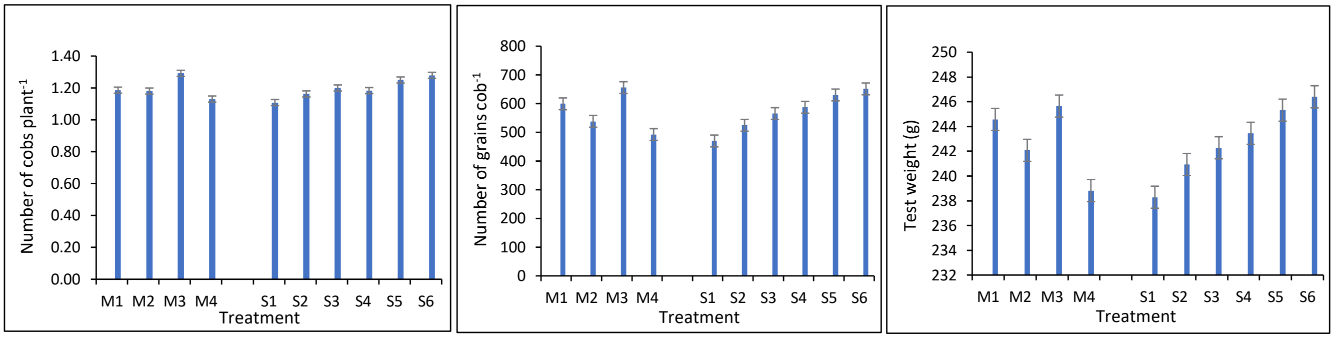

Figure 3: Effect of organic mulch and potassium fertilization on yield attributes of maize (mean of two years)

mulch, being rich in organic matter and nutrients (Demo and Asefa Bogale, 2024), improved soil health, leading to better crop growth and yield (Rossi et al., 2024; Wang et al., 2018). Similarly, the progressive increase in yields with higher potassium levels, i.e., up to 100 kg ha^{-1}, could be ascribed to the crucial role of potassium in photosynthesis, enzyme activation, assimilate translocation and water regulation, which improved nutrient use efficiency and partitioning of dry matter towards grain and stover. The split application of higher potassium doses ensured its availability during critical growth stages. Xu et al. (2020) and Csathó et al. (2025) stated significant yield improvements with adequate potassium fertilization. Non-significant variation of harvest index across mulch practices and potassium levels observed, as harvest index is largely genotype-controlled and less sensitive to agronomic practices under non-stress conditions (Jaenisch et al., 2022).

3.5. Economics of maize production

The net return (₹ ha^{-1}) and return per rupee invested (₹ ha^{-1}) varied considerably across different treatment combinations (Table 3). The highest net return and return per rupee invested were achieved under weed mulch, while potassium @ 100 kg ha^{-1} showed the highest values. Net return and return per rupee invested showed an increasing trend with higher potassium levels (S_1-S_6). However, vermicompost-mulch and weed mulch performed better in terms of production than straw mulch, while weed mulch showed economic soundness as less input was incurred.

Table 3: Effect of organic mulch and potassium fertilization on grain yield, stover yield, harvest index and economics of maize

Treatment	Grain yield (t ha^{-1})			Stover yield (t ha^{-1})			Harvest index (%)		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
Main plot (Organic mulches)									
M_1	7.48	7.21	7.34	10.31	9.55	9.93	42.32	43.1	42.71
M_2	7.55	7.31	7.43	10.84	10.37	10.60	41.15	41.31	41.23
M_3	8.53	8.34	8.44	11.18	11.21	11.19	43.42	42.71	43.06
M_4	5.75	5.53	5.64	8.19	8.04	8.12	41.38	40.6	40.99
LSD (p=0.05)	0.5	0.7	0.28	0.52	0.93	0.52	NS	NS	1.54
Sub-plot (Potassium fertilization)									
S_1	6.42	6.09	6.25	8.35	8.35	8.35	43.33	41.99	42.66
S_2	6.74	6.49	6.62	9.07	9.02	9.04	42.7	41.53	42.12
S_3	7.19	6.98	7.09	9.88	9.49	9.68	42.25	42.46	42.35
S_4	7.43	7.28	7.35	10.6	10.01	10.31	41.19	42.11	41.65
S_5	7.89	7.63	7.76	11.03	10.65	10.84	41.81	41.61	41.71
S_6	8.3	8.12	8.21	11.85	11.25	11.55	41.12	41.9	41.51
LSD (p=0.05)	0.83	0.86	0.53	1.19	0.97	0.78	NS	NS	NS
M×S (Organic mulches×Potassium fertilization)									
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Continue...

Treatment	Net return (₹ ha^{-1})			B:C ratio		
	2017-18	2018-19	Mean	2017-18	2018-19	Mean
Main plot (Organic mulches)						
M_1	64683.5	59719.2	62201.4	1.97	1.89	1.93
M_2	76214.2	71866.7	74040.4	2.35	2.27	2.31
M_3	74915.0	71817.7	73366.4	2.00	1.96	1.98
M_4	44234.3	40345.4	42289.8	1.78	1.71	1.74
LSD (p=0.05)	8494.6	11710.1	4801.59	0.15	0.20	0.08
Sub-plot (Potassium fertilization)						
S_1	49998.6	44407.0	47202.8	1.80	1.71	1.76
S_2	55380.2	51052.7	53216.4	1.88	1.81	1.85
S_3	62823.9	59127.5	60975.7	2.00	1.94	1.97
S_4	66701.7	63876.5	65289.1	2.05	2.01	2.03
S_5	74191.5	69585.2	71888.3	2.16	2.08	2.12
S_6	80974.8	77574.7	79274.7	2.25	2.20	2.22
LSD (p=0.05)	14046.2	14623.9	9007.43	0.22	0.23	0.14
M×S (Organic mulches×Potassium fertilization)						
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

NS: non-significant

4. CONCLUSION

The study revealed that under low soil temperature stress, organic mulch combined with potassium fertilization significantly enhanced maize emergence, physiological development, and yields. Vermicompost mulch consistently outperformed weed and straw mulch. Higher potassium levels enhanced the proportional increment in biomass and grain yield. Economic viability was achieved with weed mulch and higher potassium levels. Thus, these treatment combinations appeared to be effective for maximizing productivity and profitability of maize cultivation for the farming community in Eastern Sub-Himalayan region.

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