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ORIGINAL ARTICLE

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Assessing Feasible Weed Management Options in Maize under Organic Farming System of Eastern Himalayas

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ABSTRACT

Weed management under organic farming relies heavily on manual and mechanical methods, which are labour-intensive and costly, particularly in the high-rainfall hill ecosystems of North Eastern India. A field experiment was conducted for three consecutive years (2015–2017) on a long-term organic field (under organic management since 2005–06) at mid-altitude (950 m ASL) in Meghalaya to evaluate non-chemical weed management options for maize productivity, weed dynamics and soil health. Eight treatments were tested in a randomised block design, including hand weeding, mechanical weeding, soil solarization, mulching, stale seedbed preparation and maize–soybean intercropping. Among all treatments, two hand weedings at 20 and 45 days after sowing (DAS) recorded the lowest weed population (155.3/m²) and dry weight (75.3 g/m²) at 30 DAS. However, intercropping of maize with soybean (2:1) combined with one hand weeding at 45 DAS (T6) and stale seedbed + 25% reduced spacing + mulching with crop residues + one hand weeding at 45 DAS (T5) achieved significantly higher weed control efficiency at 60 DAS, the lowest weed indices (1.2 and 4.9%, respectively) and maize grain yields statistically at par with the weed-free check. T6 recorded the highest net returns (₹49,560/ha) and benefit–cost ratio (2.42), outperforming all other treatments, including the weed-free check, primarily due to lower weeding costs and the added benefit of biological nitrogen fixation by soybean. After three cropping cycles, T6 also recorded the highest soil organic carbon (22.3 g/kg), available nitrogen (272.5 kg/ha) and phosphorus (29.6 kg P_2O_5/ha), indicating concurrent improvement in soil health. Soil solarization performed poorly under the prevailing sub-32°C temperature regime of the region. Maize+soybean intercropping (2:1) with one hand weeding at 45 DAS is recommended as a practically viable, economically superior and soil health-enhancing weed management strategy for organic maize production in the North Eastern Hill Region of India.

1 | INTRODUCTION

In organic management systems, reducing weed competitiveness is essential due to limited weed control options (Das *et al*., 2016). Weeds can be managed through cultural and management practices that favor crops by altering soil biomass production (Ryan *et al*., 2010). In the North Eastern Hill Region (NEHR) of India, maize (*Zea mays* L.) is the second most important crop after rice, primarily grown under rainfed conditions (Layek *et al*., 2016). It is vital for local food security and economy, though regional yields are low due to various constraints despite high potential. Weed infestation significantly reduces maize yields, especially in high rainfall areas, with losses ranging from 28% to 100%, depending on infestation severity. Weed damage surpasses losses caused by pests like insects and diseases (Sharma *et al.*, 2010), as weeds compete for space, sunlight, moisture, and nutrients, limiting crop resource uptake (Lehoczky and Reisinger 2003; Kumar *et al*., 2013). In the NER's favorable climate with high rainfall and suitable temperatures, maize during the kharif season faces severe weed problems, especially in early growth stages from germination to 45 DAS (Saeed *et al*., 2010). Weeds also serve as hosts for pests and diseases (Essien *et al*. 2009; Das *et al*., 2016). Organic farming systems tend to exacerbate weed issues due to the use of undecomposed organic manure, mulches, and crop biomass, which promote weed growth (Ryan *et al.*, 2010; Das *et al*., 2016). As chemical control is not an option in organic systems, managing weeds relies on integrated methods that combine physical, mechanical, cultural, and biological practices to keep weeds below economic damage levels rather than complete eradication (Das *et al*., 2019). Hand weeding is common in NEHR but is labor-intensive, costly, and time-consuming, especially for small farmers (Essien *et al*., 2009; Das *et al.*, 2016). Mechanical tools, such as wheel hoes, are also promoted for timely weed removal, reducing farmer effort. Since maize weeding often overlaps with rice nursery and field prep, labor availability becomes limited. Intercropping and mulching are effective chemical-free weed control (Meshram *et al.,* 2022); for example, maize intercropped with soybean and using soybean biomass as mulch can significantly reduce weed biomass through improved ground cover and better light utilization (Sani *et al.*, 2015, Ramkrsusn, G.I., 2022). Crop residue mulch suppresses weeds by creating physical barriers and altering the microclimate, thereby enhancing maize growth and yield (Mahmood *et al.*, 2015). The stale seedbed technique involves plowing, allowing weeds to emerge, then killing them before planting, which can reduce weed density but is not sufficient alone for continuous weed control; it should be part of an integrated weed management program. Soil solarization—covering soil with plastic to heat it—also effectively controls soil-borne pests, pathogens, and weeds (Leblanc & Cloutier, 1996). Given the importance of weed management in organic farming, this study explores various non-chemical practices to examine their effects on weed dynamics, maize productivity, and soil nutrients in mid-altitude regions of the Eastern Himalayas.

HIGHLIGHTS

- Maize–soybean intercropping (2:1) with one hand weeding gave the highest net returns and B:C ratio under organic management.
- Intercropping and stale seedbed + mulching treatments matched weed-free yield without five-time hand weeding costs.
- Soybean intercropping maximised soil nitrogen, phosphorus and organic carbon after three cropping cycles.
- Non-chemical weed management combining cultural practices can sustain maize productivity in high-rainfall hill ecosystems.

2 | MATERIALS AND METHODS

The field experiment was conducted in the mid-hills of Meghalaya, India, during the rainy season (Kharif) over three consecutive years (2015-2017) with maize as the test crop. The site was under organic production since 2005-06. The soil of the field study was sandy clay loam in texture, acidic (*p*H 5.4), and high in soil organic carbon (SOC) (18.0 g/kg). While available nitrogen (N) (229.5 kg/ha) and phosphorus (P_2O_5) (24.1 kg/ha) of the soil of the experimental field were recorded to be low, available potassium (K) was medium (265.3 kg/ha). The climatic conditions of this region are subtropical, hot and humid in summer, and cold in winter. A graphical representation of average weather parameters, including maximum temperature, minimum temperature, and rainfall, for the entire experimental season of 2015- 2017 is shown in Figure 1. The monsoon usually starts from the first week of June and extends up to October, whereas the pre-monsoon showers start from April. Although there was little variation in total rainfall over the cropping cycles, total annual rainfall was at par with the 30-year average (2450 mm/year). The mean minimum and maximum temperatures at the experimental location over three years (2015-17) were 11.8 to 21.7°C and 21.6 to 29.8°C, respectively (Fig.1).

The experiment was conducted in a randomized block design (RBD) with eight weed control treatments and replicated thrice. Treatments were T_1: Two hand weeding at 20 DAS and 45 DAS, T_2: One mechanical weeding at 20 DAS + one hand weeding at 45 DAS, T_3: Soil solarization + one hand weeding at 35 DAS, T_4: Mulching with locally available weed mulch + one hand weeding at 35 DAS, T_5: Stale seedbed preparation + reduced spacing (upto 25%) + mulching with previous crop residue + one hand weeding at 45 DAS, T_6: Intercropping with soybean (2:1) + one hand weeding at 45 DAS, T_7: Weed free check (hand weeding at 15, 25, 40, 55 and 70 DAS) and T_8: Weedy check (no weeding). Mechanical weeding was performed with the help of a wheel hoe. Soil solarization was performed using a transparent polythene sheet (150 gauge) to trap solar energy and raise soil surface temperatures for 10 days. Stale seedbeds were prepared by plowing the soil to a depth of 15 cm two weeks before the normal plowing time, allowing weeds to emerge and be killed by subsequent plowing (once). Thereafter, maize (composite cv. RCM 1-61) was sown in late May–early June without further plowing the soil. Under intercropping treatment (T_6), one line/row of soybean (cv. JS 335) was grown after every two lines/rows of maize (sown at 50 cm spacing) by reducing the space in-between maize rows (additive series, without reducing the plant population of maize and incorporated in the soil at 45 DAS during earthing up of maize. The maize crop was grown with an organic nutrient source to supply the recommended dose of 80:60:40 kg N, P2O5, and K_2O/ha. Soil solarization and stale seedbed preparation were done 10–15 days and about 2 weeks before sowing, respectively. Well-decomposed farmyard manure (FYM) was used as a source of nutrients (0.5% N) on an N equivalent basis to supply the required dose of N, and rock phosphate was used to compensate for the P requirement. Soil-borne pathogens were controlled by applying neem cake at 150 kg/ha as a general dose across all treatments. Data on weeds (population, dry weight) were recorded at 30 and 60 DAS from two randomly selected quadrants (0.5 x 0.5 m) from each treatment during the maize growing period.

Weed control efficiency (WCE) and weed index (WI) were calculated using the following formulae from Mani *et al.* (1973).

$$WCE = \frac{\text{Weed dry weight in unweeded control} - \text{weed dry weight in treatment plots}}{\text{Weed dry weight in unweeded control plots}}$$

$$WI = \frac{\text{Maize yield in weed free plots} - \text{Maize yield in treatment plots}}{\text{Maize yield in weed free plots}}$$

Weed control efficiency (WCE) was calculated based on weed biomass reduction relative to the unweeded control (weedy check), whereas weed index (WI) was calculated using crop yield reduction relative to the weed-free check. Yield attributes of maize, including grain yield, were recorded for each treatment at the harvesting stage. Cost of cultivation was computed by taking the prevailing market price of the inputs during the experimental period, while gross returns were obtained by multiplying the grain yield by the market price. Composite soil samples (after 3 years) were collected initially and at the post-harvest stage from the surface layer of different plots and were analyzed for available N, P, K status, SOC, and soil microbial biomass carbon (SMBC). The soil samples collected from different treatment plots were air-dried, processed, and then passed through a 2 mm sieve to determine the availability of various nutrients in the soil. While the soil available N was measured by the alkaline permanganate method (Subbiah & Asija, 1956), the available P and K were measured by the $NaHCO_3$ extraction method (Olsen & Sommers, 1982) and neutral normal NH_4OAC extraction method (Knudsen *et al.,* 1982), respectively. The soil microbial biomass carbon (SMBC) was estimated by soil fumigation method of Anderson and Ingram (1993). The data on different parameters collected from the experiment were statistically analyzed using the analysis of variance (ANOVA) technique, with the "F" test, and the significance of treatment differences was assessed using the t-test (Gomez & Gomez, 1984). Standard error of means (SEm±) and critical difference (CD) at 5% probability (P=0.05) were calculated for each parameter studied in the experiment to evaluate differences between treatment means.

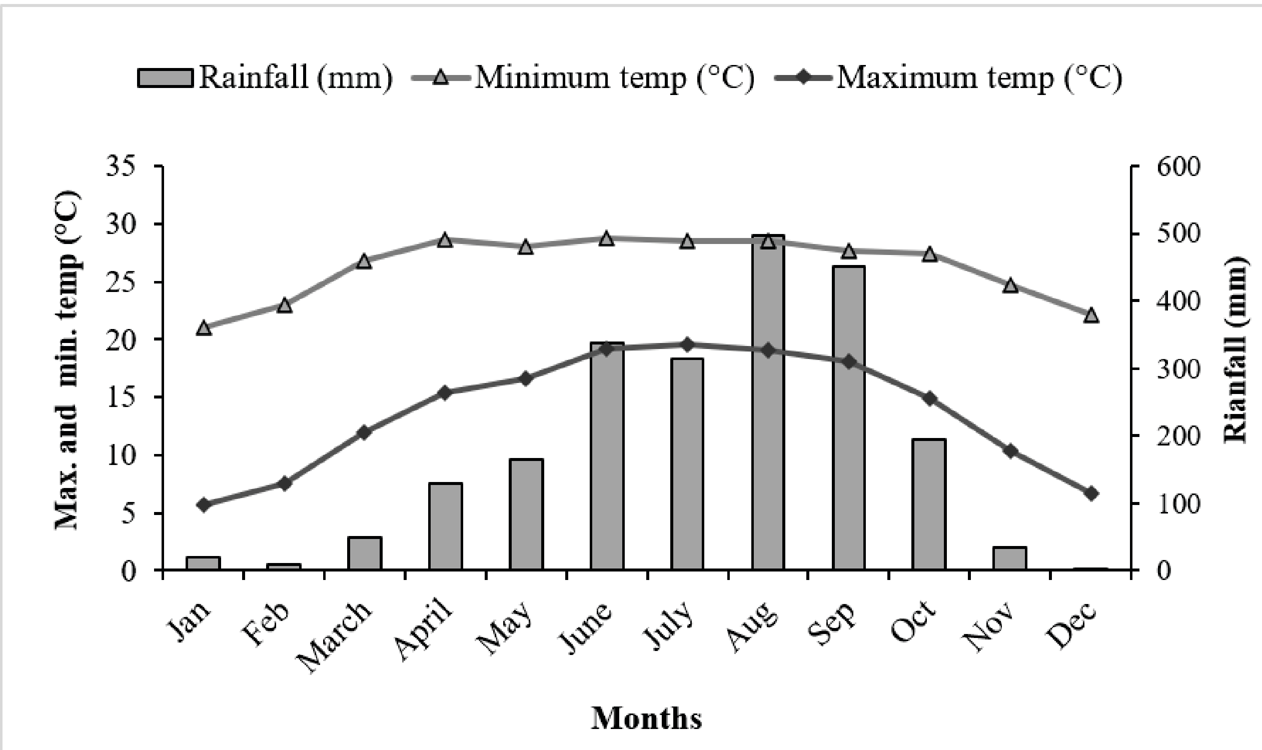

FIGURE 1 Average monthly weather parameters of the ICAR Research Complex for NEH Region, Umiam (mean data of 2015- 2017)

3 | RESULTS AND DISCUSSION

3.1 | Effect on Weed Population Dynamics and Weed Control Indices

The dominant weed species observed in the experimental period during the rainy season were classified into grasses (*Cynodon dactylon, Digitaria sanguinalis, Panicum repens, and Eleusine indica*), sedges (*Fimbristylis miliacea and Cyperus rotundus*), and broad-leaved weeds (*Ageratum conyzoides, Spilanthus acemella, Alternanthera philoxeroides, Galinsoga parviflora,* etc.). Regardless of weed control option, the highest weed count was recorded in the broad-leaved category, followed by grasses and sedges. For all weed management options, weed dry weight at 30 DAS was superior to that at 60 DAS, except for the weedy check (Table 1). Aside from the weedy check, all non-chemical weed control options were effective in reducing total weed density and dry matter (Table 1). Gul *et al*. (2009) also reported that weed biomass at 60 DAS was lower than at 30 DAS, as increased maize canopy covered the soil surface, which otherwise favored weed growth, thereby suppressing weeds at later growth stages. Minimum weed population and dry weight at 30 and 60 DAS were recorded under weed-free check (T_7). Among different non-chemical weed management options, two HW at 20 & 45 DAS (T_1) recorded significantly lower numbers of weed population (155.3/m^2) and weed dry weight (75.3 g/m^2), followed by one mechanical weeding at 20 DAS and one HW at 45 DAS (T_2) (194.0 and 85.0 g/m^2, respectively). Hand weeding is widely recognized as an effective tool for controlling weeds compared with other non-chemical weed management practices (Syawal, 1998; Khan *et al*., 1998; Das *et al*., 2016). Although the stale seedbed + 25% reduced spacing + mulching + one HW at 45 DAS (T_5) and intercropping of maize with soybean (2:1) + one HW at 45 DAS (T_6) did not reduce the weed density to a great extent at 30 DAS, but for later stages (60 DAS), the weed population decreased significantly. The treatments, *viz.* T_5 and T_6 reduced the weed population by 73 and 71% at 60 DAS, respectively, as compared to the weed-free check (T_7). This is mainly due to good land coverage from intercropping soybean (Layek *et al*. 2014a & b) and their subsequent incorporation as mulch at 45 DAS. Although the maximum WCE was recorded under weed-free conditions at 30 and 60 DAS (97.3 and 98.5%, respectively), it was not possible in actual farm conditions to keep the field completely weed-free by making five (5) HW at 15, 25, 40, 55, and 70 DAS. Among the different feasible weed management options, significantly higher WCE at 30 DAS was recorded under two HW at 20 & 45 DAS (82.8%) followed by one mechanical weeding at 20 DAS and one HW at 45 DAS (T_2) (78.7%). However, at later stages of maize growth (60 DAS), apart from weeding using HW and mechanical weeding (T_1 and T_2), intercropping with soybean + one HW at 45 DAS (T_6) and stale seedbed + reduced spacing + mulching + one HW at 45 DAS (T_5) enhanced the WCE significantly over the other non-chemical weed management options. Significantly, the lower weed index (WI) was also recorded for T_6 (1.2 %) and T_5 (4.9 %) as compared to soil solarization + one HW at 35 DAS (T_3, 18.1%). It is acknowledged that the difference in hand weeding timing (35 DAS in T3 vs. 45 DAS in T5 and T6) may have influenced treatment performance. The relatively poorer performance of the soil solarization treatment (T3) could therefore be attributed not only to suboptimal soil temperature conditions under the prevailing climate, but also to the comparatively earlier timing of hand weeding, which may not have effectively controlled later-emerging weeds.

Weed index (yield basis) was recorded the lowest under soybean intercropping (2:1) + one HW at 45 DAS followed by stale seedbed + reduced spacing (upto 25%) + mulching with previous crop residues + one HW at 45 DAS and locally available weed mulch + one HW at 35 DAS. Intercropping of soybean in between maize lines without reducing the plant population of maize (additive series), not only helps in controlling weed control but also enhances the soil fertility through biologically fixed nitrogen (*Layek et al.,* 2014a & b). Therefore, intercropping of soybean in between maize and one HW at 45 days enhanced the maize yield as compared to other treatments and recorded lower weed index.

TABLE 1 Effect of different organic weed management options on weed population density and weed control indices in maize (pooled data of 3 years)

Treatments	Weed population (number m^{-2})		Dry weight (g m^{-2})		Weed control efficiency (%)		Weed index* (yield basis)
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	
T_1: Two hand weeding (HW) at 20 and 45 DAS	155.3	75.3	7.1	6.5	82.8	89.5	7.2
T_2: One mechanical weeding (20 DAS) + one HW (45 DAS)	194.0	85.0	8.8	5.1	78.7	91.8	9.8
T_3: Soil solarization + one HW at 35 DAS	373.3	95.3	22.1	7.5	46.6	87.9	18.1
T_4: Locally available weed mulch + one HW at 35 DAS	291.0	89.3	14.0	9.5	66.2	84.7	5.9
T_5: Stale seed bed + 25% reduced spacing + mulching with previous crop residues + one HW at 45 DAS	242.0	85.7	12.3	7.2	70.2	88.4	4.9
T_6: Intercropping with soybean (2:1) + one HW at 45 DAS	234.7	91.1	15.2	6.3	63.1	89.8	1.2
T_7: Weed free check (HW at 15, 25, 40, 55 and 70 DAS)	14.7	6.3	1.1	0.9	97.3	98.5	0.0
T_8: Weedy check (no weeding)	449.0	317.0	41.3	61.9	0.0	0.0	66.8
SEm (±)	3.6	2.9	0.3	0.2	2.4	2.7	0.3
CD (P=0.05)	10.9	8.8	1.0	0.7	7.2	8.1	0.9

**Weed Index values were calculated from individual years before pooling; minor differences between WI values in Table 1 and those derived from pooled means in Table 2 result from rounding.*

3.2 | Maize Grain Yield

All the non-chemical weed control options significantly affected the pooled maize yield over the years compared with the weedy check (Fig 2). Among different weed control treatments in maize, intercropping with soybean (2:1) + one HW at 45 DAS (T_6) followed by stale seedbed + reduced spacing (upto 25%) + mulching + one HW at 45 DAS (T_5) and locally available weed mulch + one HW at 35 DAS (T_4) recorded relatively higher maize grain yield against other weed control options (*Table 2*). However, these were statistically at par with the treatment weed-free check (T_7) and treatments having two HW (T_1) and one MW and one HW (T_2). Higher maize yields under T6 and T5 may be due to enhanced soil fertility from N fixation by soybean and decomposition of mulch materials in soil, in addition to reduced weed population. The grain yield of maize was relatively higher under the maize + soybean treatment in the 1st year, and it increased significantly in subsequent years. This may be due to enhanced N availability in soil, favored by biologically fixed N from the associated intercropped soybean (Layek *et al*., 2014b). This trend of increasing maize yield over the years is also evident in the mulching treatments, *viz.,* T_4(locally available weed mulch + one HW) and T_5 (stale seed bed + mulching + one HW) (Das *et al*. 2016). Mulching with crop residues and locally available weeds not only reduces weed populations but also enriches the soil with organic carbon and available nutrients upon decomposition, thereby yielding prominent results in subsequent years (2nd and 3rd year) of the experiment (Das *et al*. 2016). Mulching helped supply nutrients and conserve soil moisture, while smothering weeds, resulting in enhanced maize yields from the 2nd year onwards. Mulch biomass, along with applied manure, might have contributed to increased maize yield (Sharma & Acharya, 2000; Sharma *et al*., 2010; Das et al., 2016). Although the highest yield was recorded under the weed-free check (T7), yield enhancement was not statistically significant compared with treatments with intercropping and mulching options (T4, T5, and T6), confirming the findings of Saini *et al*. (2013). The lowest yield was recorded in the weedy check (no weeding) (T8), followed by soil solarization + one HW at 35 DAS (T_3). As the maximum temperature in the experiment area (ICAR Umiam center) generally does not exceed 32-33°C, soil solarization could not achieve the desired results in areas with high temperatures.

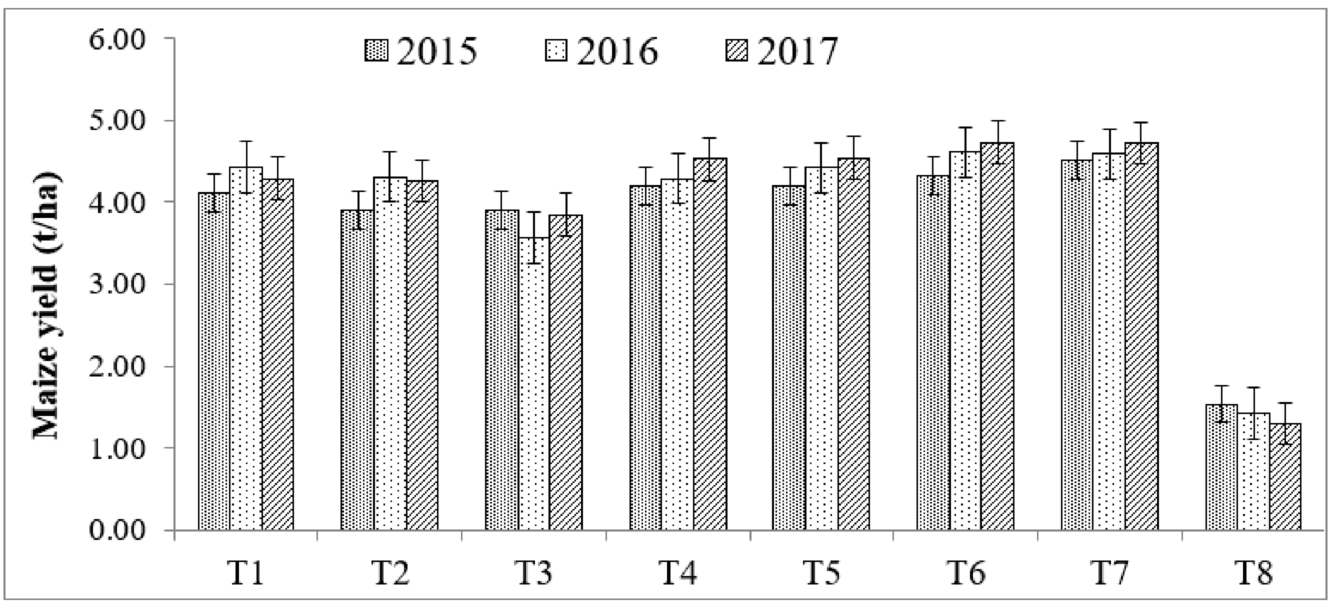

FIGURE 2 Grain yield of maize as influenced by different non-chemical weed management options over the years

Vertical bar represents both way CD (P=0.05)

T_1: Two hand weeding (HW) at 20 and 45 DAS
T_2: One mechanical weeding (20 DAS) + one HW (45 DAS)
T_3: Soil solarization + one HW at 35 DAS
T_4: Locally available weed mulch + one HW at 35 DAS
T_5: Stale seed bed + 25% reduced spacing + mulching + one HW at 45 DAS
T_6: Intercropping with soybean (2:1) + one HW at 45 DAS
T_7: Weed free check (HW at 15, 25, 40, 55 and 70 DAS)
T_8: Weedy check (no weeding)

TABLE 2 Productivity and economics of maize under different organic weed management options (pooled mean of three years)

Treatments	Maize yield ($t\ ha^{-1}$)	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
T_1: Two hand weeding (HW) at 20 and 45 DAS	4.28	36,500	79,180	42,680	2.17
T_2: One mechanical weeding (20 DAS) + one HW (45 DAS)	4.16	34,600	76,960	42,360	2.22
T_3: Soil solarization + one HW at 35 DAS	3.78	43,200	69,930	26,730	1.62
T_4: Locally available weed mulch + one HW at 35 DAS	4.34	38,500	80,290	41,790	2.09
T_5: Stale seed bed + 25% reduced spacing + mulching with previous crop residues + one HW at 45 DAS	4.38	36,970	81,030	44,060	2.19
T_6: Intercropping with soybean (2:1) + one HW at 45 DAS	4.56	34,800	84,360	49,560	2.42
T_7: Weed free check (HW at 15, 25, 40, 55 and 70 DAS)	4.61	48,600	85,285	36,685	1.75
T_8: Weedy check (no weeding)	1.42	20,500	28,305	7,805	1.38
SEm ($\pm$)	0.09	1,159	1,822	907	0.05
CD (P=0.05)	0.27	3,515	5,525	2,750	0.16

3.3 | Economics

The cost of maize cultivation was the least with one mechanical weeding at 20 DAS and one HW at 45 DAS, due to the combined use of mechanical tools and manual hand weeding, thereby reducing labor costs (Table 2). The highest cultivation cost was observed under the weed-free check (T7), followed by soil solarization + one HW (T_3). The higher cultivation costs under T7 and T3 were due to the higher labor requirements for HW (5 times) and the higher cost of transparent polythene sheet required for soil solarization. The weed-free check (T7) yielded the highest gross return (₹85,285/ha), followed by maize + soybean intercropping with one HW (T6; ₹84,360/ha) and stale seedbed + mulching + one HW (₹81,030/ha). However, the maximum net return was obtained under maize + soybean intercropping along with one HW (T_6; ₹ 49,560/ha) and stale seedbed + mulching + one HW (₹ 44,060/ha) and two hand weeding (HW) at 20 and 45 DAS (T_1; ₹ 42,680/ha). The weed-free check required five HW, which substantially increased costs; therefore, the net return under the weed-free check (T7) was substantially lower than under other weed control measures (Das *et al*., 2016). The higher net return under maize + soybean intercropping + one HW was due to the higher maize yield observed under the treatment and the lower weeding cost compared to the weed-free check (T_7). Maize intercropping with soybean recorded the highest gross and net returns due to higher maize yield owing to the supply of fixed N from the atmosphere by associated soybean and weed suppression from soybean mulch (Layek *et al*., 2014b; Das *et al*. 2016). The intercropping of maize + soybean is also known to complement each other. Maize is known as a nutrient-exhaustive crop (Ali *et al.,* 2012) and absorbs nutrients from the upper soil layers (Layek *et al.,* 2014a). Soybean, being a legume, enhances soil fertility through biological N fixation and reduces competition for soil nutrients by extracting nutrients from deeper soil strata through its taproot system (Layek *et al*., 2014b). The highest benefit cost ratio (BC ratio) was also recorded for maize + soybean intercropping + one HW (T_6; 2.42) followed by one mechanical weeding (20 DAS) + one HW (45 DAS) (T_2: 2.22) and stale seedbed + reduced spacing + mulching with previous crop residues + one HW at 45 DAS (T_5; 2.19).

3.4 | SOC and Nutrients Status in Soil

The nutrient availability in soil at the end of three years of cropping was significantly affected by different organic weed control options (Table 3). Most soil parameters, such as SOC, available N, P, K, and SMBC, improved after three cropping cycles compared with their initial levels. Intercropping with soybean (2:1) + one HW at 45 DAS (T_6) being at par with the stale seedbed + 25% reduced spacing + mulching + one HW at 45 DAS (T_5) and locally available weed mulch + one HW (T_4) recorded significantly higher SOC (22.3, 22.1 and 21.9 g/kg, respectively) after 3 cropping cycles as compared to weedy check (19.6 g/kg). The improvement under T6 can be explained through a sequence of processes. Initially, soybeans contributed to biological nitrogen fixation, which enhanced soil available nitrogen, reflected in the highest available N (272.5 kg/ha) and P (29.6 kg P_2O_5/ha) under this treatment. Part of the fixed N was utilized by crops, while the remaining contributed to residual soil fertility (Layek *et al.*, 2014b). The increased nutrient availability, along with the addition of root biomass and residues, stimulated soil microbial activity, resulting in higher microbial biomass carbon (SMBC). Although the highest SMBC was recorded under T4 (330.9 $\mu g\ g^{-1}$), it remained comparably high under T5 and T6, indicating favorable microbial conditions. Enhanced microbial activity further facilitated decomposition of organic inputs, root exudates, and incorporated biomass, ultimately leading to increased soil organic carbon (SOC). Similarly, mulching treatments (T4 and T5) improved soil properties by adding organic residues, which supplied carbon and nutrients upon decomposition (Das et al. 2016). These organic inputs also created a favorable microclimate for microbial proliferation, thereby enhancing SMBC (Ngangom *et al.*, 2020). The relative increase in SOC, available N, and P under T6 was 20.5%, 18.7%, and 22.8%, respectively, over initial values. However, available K did not differ significantly among treatments after three cropping cycles. A multi-criteria assessment (Table 4) indicated that maize + soybean intercropping (T6) performed best overall by balancing productivity, profitability, and soil health benefits, despite slightly lower weed suppression compared to the weed-free treatment.

TABLE 3 Effect of organic weed management options on soil organic carbon, microbial biomass and available nutrient after three cropping cycles

Treatments	SOC ($g\ kg^{-1}$)	Availiable N ($kg\ ha^{-1}$)	Availiable P_2O_5 ($kg\ ha^{-1}$)	Availiable K_2O ($kg\ ha^{-1}$)	SMBC ($\mu g\ g^{-1}$ dry soil)
T_1: Two hand weeding (HW) at 20 and 45 DAS	20.9	241.1	26.9	274.3	288.3
T_2: One mechanical weeding (20 DAS) + one HW (45 DAS)	19.8	238.4	26.6	271.5	279.9
T_3: Soil solarization + one HW at 35 DAS	19.7	231.2	25.2	261.6	271.3
T_4: Locally available weed mulch + one HW at 35 DAS	21.9	249.3	28.2	283.2	330.9
T_5: Stale seed bed + 25% reduced spacing + mulching with previous crop residues + one HW at 45 DAS	22.1	253.7	28.9	285.1	327.2
T_6: Intercropping with soybean (2:1) + one HW at 45 DAS	22.3	272.5	29.6	271.5	315.3
T_7: Weed free check (HW at 15, 25, 40, 55 and 70 DAS)	21.0	241.2	27.2	275.3	278.2
T_8: Weedy check (no weeding)	19.6	237.2	24.2	271.3	303.6
Initial value	18.0	229.5	24.1	265.3	242.1
SEm (±)	0.7	6.1	0.8	9.3	7.6
CD (P=0.05)	2.1	18.6	2.5	NS	23.2

TABLE 4 Comparative performance of weed management treatments across key criteria (pooled basis)

Treatments	Weed suppression	Yield performance	Net return	B:C ratio	Soil health improvement	Overall ranking
T1: Two hand weeding (HW) at 20 and 45 DAS	High	Medium	Medium	Medium	Medium	Moderate
T2: One mechanical weeding (20 DAS) + one HW (45 DAS)	High	Medium	Medium	High	Medium	Moderate
T3: Soil solarization + one HW at 35 DAS	Low	Low	Low	Low	Low	Poor
T4: Locally available weed mulch + one HW at 35 DAS	Medium	Medium-High	Medium	Medium	High	Good
T5: Stale seed bed + 25% reduced spacing + mulching with	Medium-High	High	High	High	High	Very good
T6: Previous crop residues + one HW at 45 DAS	Medium-High	High	Highest	Highest	Highest	Best
T7: Intercropping with soybean (2:1) + one HW at 45 DAS	Highest	Highest	Medium	Low	Medium	Good (not practical)
T8: Weed free check (HW at 15, 25, 40, 55 and 70 DAS)	Very low	Very low	Very low	Low	Low	Poor

4 | CONCLUSIONS

A three-year experiment in Meghalaya's organic maize system shows that effective weed management is possible without total eradication, using a mix of cultural and mechanical practices. Among non-chemical options, maize–soybean intercropping (2:1) with one weeding at 45 DAS proved most viable, yielding 4.56 t/ha and matching weed-free yields, with the lowest weed index (1.2%), highest net returns (₹49,560/ha), and benefit–cost ratio (2.42). Soybean's dual role—canopy cover and nitrogen fixation—enhances weed suppression and soil health, with benefits accumulating over three cycles. Second-best was a stale seedbed with 25% reduced spacing, mulching, and one weeding at 45 DAS, providing good weed control and soil carbon, suited for farmers unable to intercrop. Two hand weedings at 20 and 45 DAS effectively suppressed weeds but with higher labour costs. Soil solarization was ineffective due to regional temperatures (~32–33°C). Treatments with soybean intercropping and mulching improved soil organic carbon, nitrogen, and phosphorus, emphasizing the importance of soil health in organic weed management. Overall, maize–soybean intercropping with one weeding is recommended for India's northeastern high-rainfall hill regions, where not feasible, stale seedbed with reduced spacing, mulching, and weeding offers a reliable alternative.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR'S CONTRIBUTION

Conceptualization and supervision: A.D.; Investigation and data collection: J.L., K.R., S.P., R.T., and L.G.M.; Data analysis and interpretation: J.L. and A.D.; Manuscript drafting: J.L.; Manuscript review and editing: A.D., P.B., S.B., R.G., and J.S. All authors have read and approved the final version of the manuscript.

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