



RESEARCH ARTICLE

Organic nutrient integration and mulching as sustainable strategies for maize and cluster bean intercropping

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Abstract

A field experiment was conducted during the summer season of 2025–26 to evaluate the effects of integrated organic nutrient management, mulching and organic foliar sprays on growth, physiological traits and productivity of the maize-cluster bean intercropping system. The experiment was conducted in a split-plot design with 3 replications, comprising different mulching practices combined with enriched vermicompost and humic acid, along with various organic foliar formulations. Observations on plant height, dry matter production, leaf area index (LAI), soil plant analysis development (SPAD) chlorophyll content and yield parameters were recorded. Results revealed that spread mulching combined with enriched vermicompost and humic acid (M₁) significantly improved the plant height (216.7 cm) at harvest, LAI (2.74) at 90 days after sowing (DAS), SPAD (53.09) at 90 DAS, dry matter production (15321 kg ha⁻¹) at harvest and grain yield (5508 kg ha⁻¹) in maize compared with other treatments. Among organic foliar treatments, 3 % organic formulation (1 : 1 : 1) mixture of Panchagavya, fermented egg extract (FEE) and fermented fish extract (FFE) (S₄) registered superior performance with maximum plant height (237 cm), LAI (2.44), SPAD value (53.82) and grain yield (6064 kg ha⁻¹) compared with other treatments. A similar trend was also observed in cluster bean under integrated organic nutrient management and foliar spray treatments. The main effects of mulching and organic foliar spray treatments were significant; however, their interaction was non-significant. The findings demonstrate that enriched organic nutrient sources, mulching and organic foliar formulations is an effective and sustainable strategy for improving productivity and resource-use efficiency in maize-cluster bean intercropping systems.

Keywords: chlorophyll; crop productivity; enriched vermicompost; foliar formulations; humic acid; intercropping; split plot design

Introduction

Maize is a major cereal crop globally and is the third most consumed cereal after wheat and rice (1). It is estimated that it is grown 150–180 million ha in approximately 160–165 countries and production is estimated at 1.2 billion tonnes annually (2). Maize is grown in India on around 11.5–12.0 million hectares, yielding over 42 million tonnes with an average productivity of 3.6–3.7 t ha⁻¹ (3). Continuous reliance on inorganic fertilisers has reduced soil organic carbon, disrupted nutrient balance, lowered microbial activity and accelerated soil degradation, posing challenges to long-term agricultural sustainability. Heavy use of chemical fertilisers alone causes soil deterioration and the degradation of soil and organic matter (4). The addition of *Azospirillum*, phosphobacteria, arbuscular mycorrhizal fungi (AMF), rock phosphate and neem cake to the vermicompost enhance nutrient cycling in plant by increasing nitrogen (N) fixation and phosphorus (P) solubilisation.

Vermicompost provides plant accessible nutrients such as N, P, potassium (K), calcium (Ca) and magnesium (Mg) and has possesses high moisture-holding capacity, a fine particle structure, robust microbial and enzyme activities and richness in vitamins and enzymes (5). Humic acid has a positive effect on the growth of

plants, with the ability to raise levels of plant growth promoting hormones such as auxin and cytokinin which have roles in plant stress resistance, nutrients metabolism and photosynthesis (6). Organic residue mulching also enhances water holding capacity, soil structure and microbial activity and root development, which leads to higher physiological efficiency and biomass production (7). Organic formulations applied foliarly can rapidly deliver nutrients during critical growth phases. Fermented egg extract (FEE) and fermented fish extract (FFE) contain high content of amino acids and nutrients which can stimulate the synthesis of chlorophyll, photosynthetic activity and crop productivity (8, 9).

Cereal-legume intercropping systems have been widely recognised for improving resource-use efficiency, nutrient cycling, yield stability and land productivity. Legume intercrops can enhance the biological N fixation from 20–60 kg N ha⁻¹, which in turn would enhance soil fertility and decrease the need for external N inputs (10). Cluster bean (*Cyamopsis tetragonoloba* L.) is an important drought tolerant legume crop that supplies N to the soil, boosts microbial activity and intercropping system comprising cereals and legumes promote sustainable agriculture through symbiotic N fixation (11). The land equivalent ratio (LER), nutrient use efficiency (NUE) and overall system productivity have been

reported to be better with maize introduction into intercrops with legumes, compared with maize monocrop and reduced risks from monocropping (12).

Despite documented benefits of organic nutrient sources, mulching and organic foliar formulations individually, limited information is available on their combined effects in maize-cluster bean intercropping systems. The present study was undertaken to evaluate the influence of integrated organic nutrient management, mulching practices and organic foliar formulations on growth, physiological attributes and productivity of maize and cluster bean under intercropping conditions.

Materials and Methods

Experimental location

A field experiment was conducted in field No.36C of Eastern Block Farm at Agricultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore (11°04'8" N latitude and 76°45' E longitude with an altitude of 426.9 m above the mean sea level), during the summer season (19 December–2 April) 2025–26. The weather conditions prevailing during the crop growth period were characterised by a mean maximum temperature of 30.41 °C, mean minimum temperature of 17.27 °C, relative humidity of 69.64 % and total rainfall of 11.08 mm, with a mean daily rainfall of 0.15 mm day⁻¹. The mean solar radiation and wind speed recorded during the experimental period were 19.31 MJ m⁻² day⁻¹ and 1.74 m s⁻¹. The experimental soil was clay loam in texture. Prior to the initiation of the experiment, composite soil samples were collected from the surface soil layer (0–15 cm depth) of the experimental field and analysed for their initial physico-chemical properties of the experimental soil are presented in Table 1. Maize hybrid COH (M) 6 and cluster bean variety MDU 1 were grown under a 2 : 1 intercropping system, consisting of two rows of maize alternated with one row of cluster bean. Maize was sown at a spacing of 60 × 25 cm with a seed rate of 20 kg ha⁻¹, while cluster bean was maintained at a spacing of 30 × 10 cm with a seed rate of 10 kg ha⁻¹. The corresponding plant populations were approximately 66667 plants ha⁻¹ for maize and 333333 plants ha⁻¹ for cluster bean. The experiment was laid out in a split-plot design with 3 replications and each plot measured 4 × 5 m (20 m²). Observations like plant height (cm), leaf area (cm²), SPAD, dry matter (kg ha⁻¹), grain yield (kg ha⁻¹) and yield attributes were recorded at 60 days after (DAS), 90 DAS and harvest stage. A life irrigation was given immediately

after sowing, followed by irrigations at 7-day intervals throughout the crop growth period.

Treatment details

The field experiment was laid out in a split plot design with 3 replications involving 15 treatments. Enriched vermicompost and humic acid were applied uniformly to all main plot treatments, while mulching type served as the main treatment factor. Organic foliar spray treatments were imposed as subplot treatments. Foliar sprays were applied at 30, 45 and 60 DAS. The treatment details are presented in Table 2.

Preparation of enriched vermicompost

Enriched vermicompost was prepared using 1.5 tonnes of well-decomposed vermicompost, rock phosphate (50 kg), neem cake (20 kg), arbuscular mycorrhizal fungal (AMF) (2 kg), *Azospirillum* (2 kg), phosphobacteria (2 kg) and *Azotobacter* (2 kg) were added and mixed thoroughly. Water was sprinkled to maintain moisture and the mixture was covered with gunny bags under shaded conditions. It was incubated for 20 days with turning at 3–5 days interval. After enrichment, the vermicompost was applied as a basal dose before sowing at 12.4 t ha⁻¹ (25 kg plot⁻¹) and incorporated into the soil during final land preparation (13). The enriched vermicompost at 12.4 t ha⁻¹ was estimated to supply 223.2 kg N ha⁻¹, based on its N content of 1.8 %.

Mulching material

Mulching treatments were applied using dried maize stover residues containing approximately 8–10 % moisture content at 15 DAS to conserve soil moisture and improve crop growth. In spread mulching (M₁), maize was evenly spread over ridges and furrows at 10 kg plot⁻¹ with a thickness of about 5–7 cm. In bundle mulching (M₂), maize stover was applied at the same rate (10 kg plot⁻¹) but arranged in bundles of about 15–20 cm width and 5–7 cm thickness over ridges and furrows. (14). It reduces soil moisture loss through evaporation, improves soil water retention, moderates soil temperature, suppresses weed growth, enhances nutrient availability and creates a favourable microclimate for improved growth, physiological performance and yield of maize and intercrop cluster bean.

Humic acid application

Humic acid in granular form was procured from TAAS Agro Marketers, Tiruvannamalai, Tamil Nadu, India and applied as a soil application at 3 kg ha⁻¹ (6 g plot⁻¹) along with enriched vermicompost during final land preparation before sowing. The product contained 50 % humic acid derived from potassium humate, while the remaining 50 % consisted of inert carrier materials and other formulation constituents. Humic acid was applied to improve nutrient uptake, root growth and soil microbial activity. 3 % panchagavya, 2 % FEE, 2 % FFE were procured from Nammazhvar Organic Farming Research Centre, Tamil Nadu Agricultural University, Coimbatore.

Table 1. Initial physico-chemical properties of the experimental soil

Parameter	Value
pH	8.4 (Alkaline)
Electrical conductivity (dS m ⁻¹)	1.47 (Non-saline)
Available nitrogen (kg ha ⁻¹)	191.6 (Low)
Available phosphorus (kg ha ⁻¹)	14.5 (Medium)
Available potassium (kg ha ⁻¹)	549.3 (High)
Organic carbon (%)	0.45 (Low)

Table 2. Treatment details

Main plot (Organic nutrients and mulching)	
M ₁	Enriched vermicompost + humic acid + spread mulching
M ₂	Enriched vermicompost + humic acid + bundle mulching
M ₃	Enriched vermicompost + humic acid + no mulching
Sub plot (Organic foliar spray)	
S ₁	3 % panchagavya
S ₂	2 % Fermented egg extract (FEE)
S ₃	2 % Fermented fish extract (FFE)
S ₄	3 % organic formulation (1 : 1 : 1) mixture of panchagavya, FEE and FFE
S ₅	Control (no organic foliar spray)

Plant height

Plant height is measured from the soil surface to the tip of the uppermost fully expanded leaf and expressed in centimetres (cm).

Leaf area index (LAI)

The leaf area index (LAI), an essential measure of the crop canopy, was calculated using the formula,

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Ground area covered by the plant (cm}^2\text{)}}$$

The leaf area was measured for the 5 selected plants at different crop growth stages and the average LAI was computed for each treatment plot. This parameter serves as an indicator of the crop's efficiency in capturing sunlight and conducting photosynthesis.

Soil plant analysis development (SPAD) chlorophyll meter reading (SCMR)

Chlorophyll content was measured using a SPAD chlorophyll meter (Konica Minolta, Japan) to assess the photosynthetic potential and overall plant health of maize. Chlorophyll content was recorded from the physiologically active leaves of five tagged plants in each plot at different crop growth stages. The SPAD readings were averaged and expressed as SPAD chlorophyll meter readings (SCMR) for each treatment.

Dry matter production

Plant samples for estimating dry matter production were collected at 60 DAS, 90 DAS and at harvest. Five plants from each treatment were randomly selected and uprooted carefully at ground level. The collected samples were first air dried and then oven dried at $80 \pm 5^\circ\text{C}$ until a constant weight was attained. The dry matter production was computed and expressed in kilogram per hectare (kg ha^{-1}).

Yield parameters

Observations were recorded from each treatment. Grain yield and straw yield were accounted for after harvest in the net plots and the harvest index was worked out per standard procedure. The grains from each net plot (after removing the border and sampling

rows) were collected.

Harvest index (HI)

Harvest index (HI) was worked out by the formula (15):

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

Statistical analysis

The data pertaining to the experiment were subjected to statistical analysis by analysis of variance (ANOVA) method (16). The data were statistically analysed using R software. Statistical analysis was performed using R software (version 4.6.0). The ANOVA appropriate for a split-plot design was carried out to test the significance of treatment effects. Treatment means were compared using the critical difference (CD) test at the 5 % level of significance ($p \leq 0.05$). Pearson's correlation coefficients were computed using individual plot observations from all treatment combinations and replications ($n = 45$) to determine the relationships among growth, physiological and yield parameters of maize.

Results

Growth parameters

Plant height was significantly affected ($p \leq 0.05$) by organic nutrient management, mulching practices and foliar organic formulations throughout the crop growth period (Table 3). Among the main treatments, enriched vermicompost + humic acid + spread mulching (M_1) recorded the highest plant height at 60 DAS (159.0 cm), at 90 DAS (190.6 cm) and at harvest (216.7 cm), while the minimum values occurred under the enriched vermicompost + humic acid + no mulching (M_3) treatment at 60 DAS (144.6 cm), at 90 DAS (166.7 cm) and at harvest (191.9 cm). Plant height also varied significantly among the organic foliar spray treatments, with 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recording the highest values at 60 DAS (179.9 cm), at 90 DAS (212.7 cm) and at harvest (237.0 cm), whereas the control treatment (S_5) recorded the lowest plant height at 60 DAS (126.1 cm), at 90 DAS (142.8 cm) and at harvest (180.7 cm). A similar trend was observed for dry matter accumulation. Among the main

Table 3. Effect of enriched organic nutrient management, mulching and foliar spray on plant height and dry matter production (DMP) of maize

Plant height (cm)	Dry matter production (kg ha^{-1})					
	60 DAS	90 DAS	At harvest	60 DAS	90 DAS	At harvest
Main plot (Organic nutrients and mulching)						
M_1	159.0	190.6	216.7	8022	12594	15321
M_2	158.4	188.8	211.8	7364	12486	14019
M_3	144.6	166.7	191.9	6948	11546	13005
SED	3.21	3.72	4.45	195.6	232	250.7
CD (5 %)	8.92	10.34	12.37	543.8	644.9	697.0
Sub plot (Organic foliar spray)						
S_1	154.3	184.5	206.7	7741	12491	14943
S_2	144.7	172.6	189.6	6847	10914	12998
S_3	165.0	197.6	220.0	7989	12807	14726
S_4	179.9	212.7	237.0	9079	14307	16349
S_5	126.1	142.8	180.7	5566	10525	11559
SED	4.36	4.48	6.42	178.5	443.1	391.6
CD (5 %)	9.03	9.27	13.29	369.6	917.2	810.6
M X S						
SED	7.55	7.76	11.12	309	767.48	678
CD (5 %)	NS	NS	NS	NS	NS	NS
S X M						
SED	7.45	7.88	10.89	338	724.59	656
CD (5 %)	NS	NS	NS	NS	NS	NS

DAS: days after sowing; NS: not significant.

treatments, enriched vermicompost + humic acid + spread mulching (M_1) recorded the highest dry matter accumulation at 60 DAS (8022 kg ha⁻¹), at 90 DAS (12594 kg ha⁻¹) and at harvest (15321 kg ha⁻¹), whereas the lowest values were observed in enriched vermicompost + humic acid + no mulching (M_3) at 60 DAS (6948 kg ha⁻¹), at 90 DAS (11546 kg ha⁻¹) and at harvest (13005 kg ha⁻¹). Among the organic foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recorded the highest dry matter accumulation at 60 DAS (9079.1 kg ha⁻¹), at 90 DAS (14307 kg ha⁻¹) and at harvest (16349 kg ha⁻¹), whereas the control treatment (S_5) recorded the lowest dry matter accumulation at 60 DAS (5566 kg ha⁻¹), at 90 DAS (10525 kg ha⁻¹) and at harvest (11559 kg ha⁻¹).

Physiological traits

The reduction in LAI towards crop maturity may be attributed to leaf senescence and redistribution of assimilates from vegetative tissues to developing reproductive organs (Fig. 1). Among the main treatments, enriched vermicompost + humic acid + spread mulching (M_1) recorded the highest LAI values at 60 DAS (3.55) and at 90 DAS (2.74), whereas enriched vermicompost + humic acid + no mulching (M_3) recorded the minimum values at 60 DAS (3.13) and at 90 DAS (2.41). Among the organic foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recorded the highest LAI at 60 DAS (4.03) and at 90 DAS (3.14), whereas the control treatment (S_5) showed the lowest LAI at 60 DAS (2.77) and at 90 DAS (2.05).

In Fig. 2, SPAD values of maize increased from 60–90 DAS across all treatments, indicating progressive improvement in chlorophyll concentration and photosynthetic activity during crop growth. Significant differences among treatments were observed at both growth stages. Among the main treatments, enriched vermicompost + humic acid + spread mulching (M_1) consistently recorded the highest SPAD values at 60 DAS (49.48) and at 90 DAS (53.09), followed by enriched vermicompost + humic acid + bundle mulching (M_2) at 60 DAS (47.12) and at 90 DAS (51.55), whereas the lowest SPAD values were recorded in enriched vermicompost + humic acid + no mulching (M_3) at 60 DAS (44.47) and at 90 DAS (49.72). Among the organic foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recorded the highest SPAD values at 60 DAS (53.43) and at 90 DAS

(53.82), whereas the control treatment (S_5) recorded the minimum SPAD values at 60 DAS (42.61) and at 90 DAS (49.12). The remaining treatments showed intermediate performance. The SED and CD (5 %) values confirmed significant treatment effects on SPAD values at both growth stages.

Yield attributes and productivity

Impact of organic nutrient management, mulching and organic foliar spray on grain yield and yield attributes are presented in (Table 4). Cob length recorded higher values in enriched vermicompost + humic acid + spread mulching (M_1) (19.02 cm), followed by enriched vermicompost + humic acid + bundle mulching (M_2) (17.50 cm), whereas the lowest value was noted in enriched vermicompost + humic acid + no mulching (M_3) (16.24 cm). Cob girth was higher in enriched vermicompost + humic acid + spread mulching (M_1) (15.25 cm), followed by enriched vermicompost + humic acid + no mulching (M_3) (13.58 cm). The absence of significant differences in test weight and harvest index suggests that treatment effects primarily influenced sink size and biomass production rather than grain filling efficiency. Grain yield was higher in enriched vermicompost + humic acid + spread mulching (M_1) (5508 kg ha⁻¹), followed by enriched vermicompost + humic acid + bundle mulching (M_2) (5042 kg ha⁻¹), whereas the lowest grain yield was recorded in enriched vermicompost + humic acid + no mulching (M_3) (4725 kg ha⁻¹). Stover yield was also higher in enriched vermicompost + humic acid + spread mulching (M_1) (9879 kg ha⁻¹), whereas the lowest value was observed in enriched vermicompost + humic acid + no mulching (M_3) (8291 kg ha⁻¹). Higher grain and stover yield observed under enriched vermicompost + humic acid + spread mulching (M_1) may be attributed to improved soil moisture conservation, enhanced nutrient availability and increased photosynthetic efficiency throughout crop growth. Among the organic foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recorded the highest cob length (19.79 cm), followed by 2 % fermented fish extract (FFE) (S_3) (18.65 cm), which was on par with 3 % panchagavya (S_1) (18.24 cm), whereas the lowest value was recorded in the control treatment (S_5) (15.09 cm). Cob girth was also higher in 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) (15.11 cm), followed by 2 % fermented fish extract (FFE) (S_3) (14.39 cm), whereas the lowest value was recorded in the control

Table 4. Effect of integrated organic nutrient management on grain yield of maize under maize-cluster bean intercropping system yield parameter

Yield attributes								
Treatment	Cob length	Cob girth	No of rows per cob	No of grains per cob	Test weight	Harvest index	Yield	Stover yield
Main plot (Organic nutrients and mulching)								
M_1	19.00	15.25	14.69	506.9	29.00	0.38	5508	9879
M_2	17.50	13.41	14.22	454.6	29.41	0.40	5042	9076
M_3	16.24	13.58	14.25	403.8	29.11	0.38	4725	8291
SED	0.35	0.31	0.27	11.21	0.57	0.01	102.6	200.4
CD (5 %)	0.97	0.86	NS	31.16	NS	NS	285.2	557.2
Sub plot (Organic foliar spray)								
S_1	18.24	14.33	14.31	480.3	29.60	0.40	5346	9719
S_2	16.14	14.28	14.13	429.4	29.37	0.39	4538	8504
S_3	18.65	14.39	14.39	461.6	28.78	0.39	5461	9376
S_4	19.79	15.11	14.97	523.1	29.63	0.39	6064	10284
S_5	15.09	12.29	14.13	381.2	28.49	0.38	4051	7527
SED	0.55	0.57	0.40	11.13	1.00	0.01	183.5	286.7
CD (5 %)	1.14	1.18	NS	23.04	NS	NS	379.8	593.6
M X S								
SED	0.95	0.98	0.68	19.28	1.74	0.01	317.8	496.7
CD (5 %)	NS	NS	NS	NS	NS	NS	NS	NS
S X M								
SED	0.92	0.92	0.66	20.58	1.65	0.01	302.2	487.4
CD (5 %)	NS	NS	NS	NS	NS	NS	NS	NS

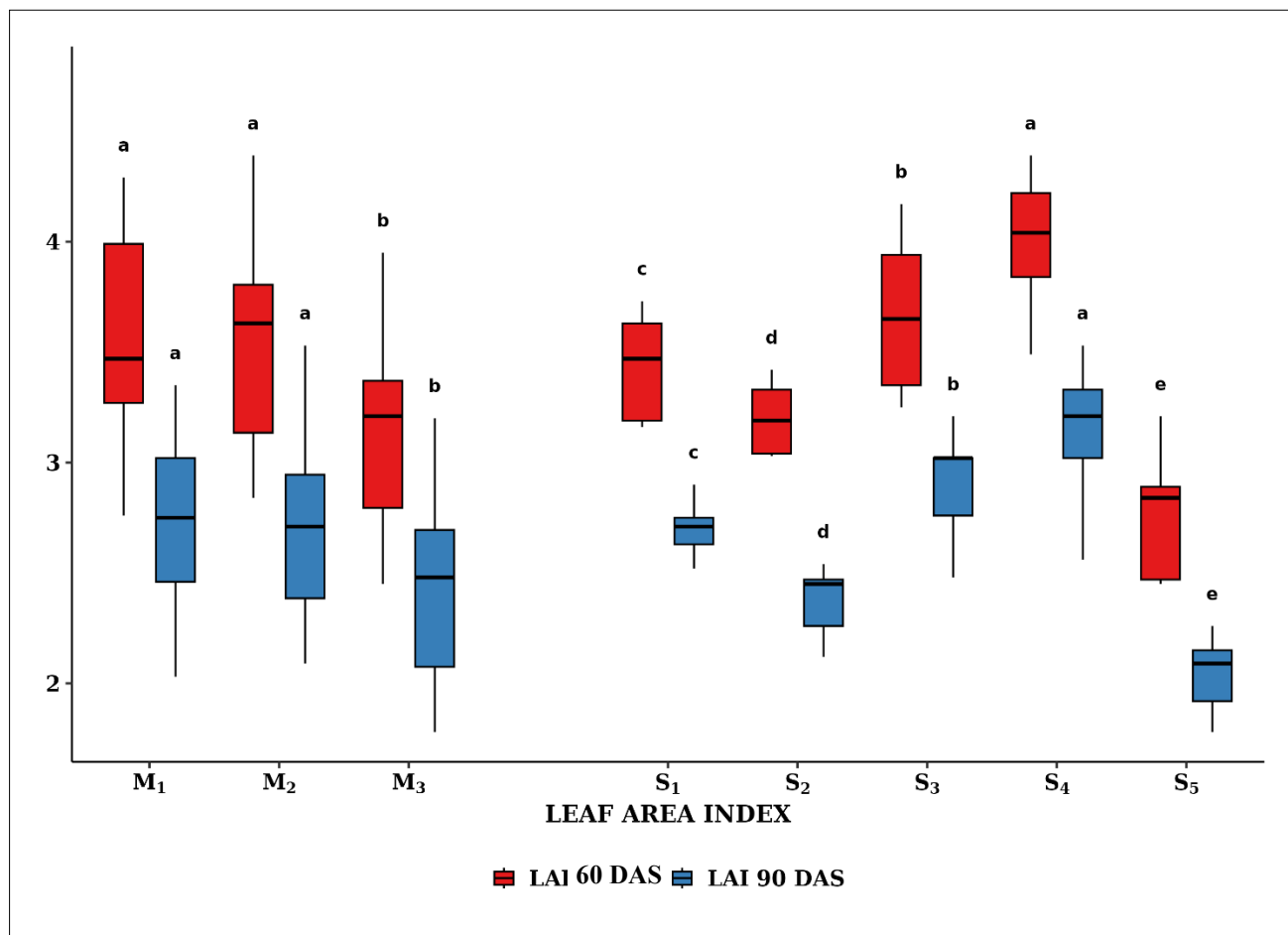


Fig. 1. Influence of integrated organic nutrient management on leaf area index (LAI) of maize at different growth stages.

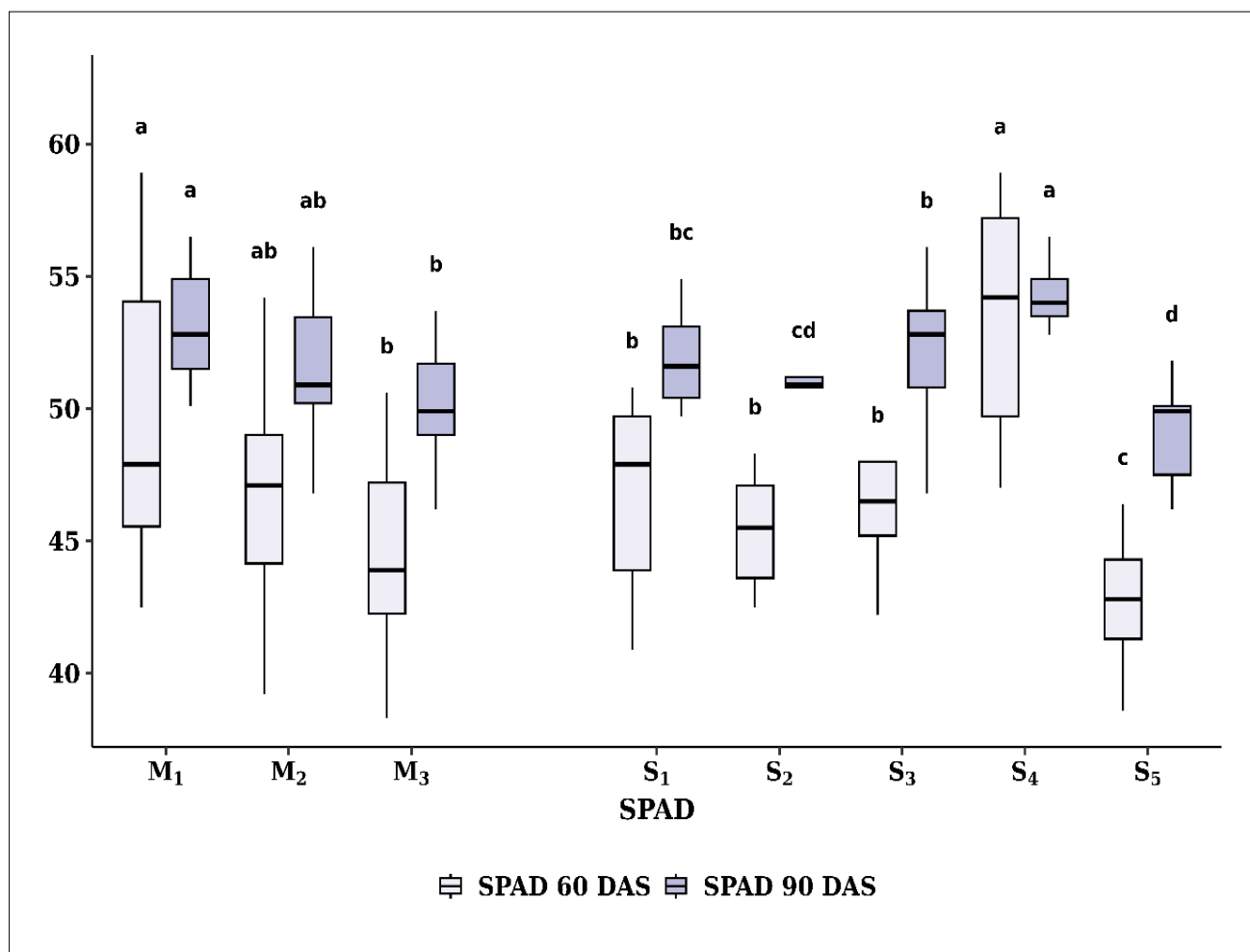


Fig. 2. Effect of organic nutrient management and foliar formulations on soil plant analysis development (SPAD) chlorophyll values of maize.

treatment (S_5) (12.29 cm). Grain yield was highest in 3 % organic formulation (S_4) (6064 kg ha⁻¹), whereas the lowest grain yield was recorded in the control treatment (S_5) (4051 kg ha⁻¹). Similarly, stover yield was higher in 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) (10284 kg ha⁻¹), whereas the lowest stover yield was observed in the control treatment (S_5) (7527 kg ha⁻¹). Interaction effects remained non-significant for all yield attributes.

Performance of cluster bean under intercropping

Plant height increased progressively throughout crop growth, with significant differences observed among organic nutrient management and foliar spray treatments (Table 5). Among the main treatments, enriched vermicompost + humic acid + spread mulching (M_1) recorded the highest plant height at 60 DAS (39.82 cm) and at harvest (76.65 cm), whereas enriched vermicompost + humic acid + no mulching (M_3) recorded the lowest plant height at harvest (68.06 cm). Dry matter production increased continuously with crop growth. Higher dry matter accumulation was recorded in enriched vermicompost + humic acid + spread mulching (M_1) at 60 DAS (604 kg ha⁻¹) and at harvest (952 kg ha⁻¹), whereas enriched vermicompost + humic acid + no mulching (M_3) recorded the lowest values at 60 DAS (550 kg ha⁻¹) and at harvest (861 kg ha⁻¹). Among the organic foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) maintained the highest dry matter production at 60 DAS (620 kg ha⁻¹) and at harvest (991 kg ha⁻¹), whereas the control treatment (S_5) recorded lower values at 60 DAS (533 kg ha⁻¹) and at harvest (834 kg ha⁻¹). Vegetable yield was highest in enriched vermicompost + humic acid + spread mulching (M_1) (2089 kg ha⁻¹), whereas enriched vermicompost + humic acid + no mulching (M_3) recorded the minimum yield (1790 kg ha⁻¹). Among the foliar spray treatments, 3 % organic formulation (1 : 1 : 1) consisting of panchagavya, FEE and FFE (S_4) recorded the highest vegetable yield (2230 kg ha⁻¹), whereas the control treatment (S_5) recorded the lowest yield (1667 kg ha⁻¹). Interaction effects remained non-significant.

Discussion

Effect of treatments on growth parameter

The application of organic nutrient sources along with mulching significantly enhanced plant growth and biomass accumulation in maize. Similar findings were reported in early results (17). Mulching

improves the crop microenvironment by conserving soil moisture, moderating soil temperature and enhancing water-use efficiency, resulting in improved leaf expansion and biomass accumulation (18). The enhanced plant height and dry matter accumulation observed under enriched vermicompost + humic acid + spread mulching (M_1) may be attributed to improved nutrient availability, increased microbial activity and better soil moisture conservation, which collectively improve nutrient uptake and biomass production. It has been established that effective microorganism (EMO) cultures synthesise phytohormones such as auxins and other growth regulators, which stimulate maize growth. Panchagavya is rich in beneficial effective microorganisms (EMOs), growth-promoting substances and nutrients that enhance crop growth and physiological performance (19). Previous studies indicate that the foliar application of 3 % panchagavya significantly improves grain yield, further demonstrating its potential as a low-cost organic input. The increased plant height observed under organic foliar treatments in the present study may be attributed to improved nutrient availability, enhanced cell division and increased metabolic activity induced by fermented organic extracts (20). That panchagavya application increased plant height due to growth-promoting enzymes stimulating rapid cell division and multiplication. The amino acids and bioactive compounds present in fermented fish extract may stimulate N assimilation, chlorophyll synthesis and carbon metabolism, leading to greater biomass production. In contrast, the control treatment recorded comparatively lower plant height and biomass accumulation due to the absence of supplemental organic nutrient inputs (21).

Effect of treatments on physiological traits

Higher LAI and SPAD values observed under enriched vermicompost + humic acid + spread mulching (M_1) and 3 % organic formulation (S_4) may be associated with improved nutrient availability, enhanced chlorophyll synthesis and prolonged retention of photosynthetically active leaves. Organic foliar formulations containing panchagavya, FEE and FFE provide amino acids, micronutrients and growth-promoting substances that enhance leaf expansion and chlorophyll biosynthesis, thereby improving photosynthetic efficiency and biomass accumulation. Foliar nutrient application enhances chlorophyll synthesis by supplying readily available N and micronutrients to actively growing tissues (22). Similarly, higher

Table 5. Response of cluster bean yield to organic nutrient management and mulching treatments under intercropping

Treatment	Plant height (cm)		Dry matter production kg ha ⁻¹		Vegetable yield (kg ha ⁻¹)
	60 DAS	At harvest	60 DAS	At harvest	
Main plot (Organic nutrients and mulching)					
M ₁	39.82	76.65	604	952	2089
M ₂	36.63	75.76	597	921	1971
M ₃	33.56	68.06	550	861	1790
SED	0.76	1.41	10.30	19.80	39.87
CD (5 %)	2.11	3.92	28.63	55.04	110.84
Sub plot (Organic foliar spray)					
S ₁	37.22	76.40	592	932	1941
S ₂	34.83	69.42	571	855	1839
S ₃	38.73	77.73	602	945	2074
S ₄	41.95	79.38	620	991	2230
S ₅	30.62	64.56	533	834	1667
SED	0.85	2.14	15.67	18.84	49.78
CD (5 %)	1.76	4.43	32.44	39	103.0
M X S					
SED	1.48	3.71	27.14	32.63	86.22
CD (5 %)	NS	NS	NS	NS	NS
S X M					
SED	1.53	3.61	26.36	35.27	86.22
CD (5 %)	NS	NS	NS	NS	NS

chlorophyll content in tomato leaves was attributed to growth-regulating substances and essential nutrients present in panchagavya-based formulations. Enhanced LAI and chlorophyll content likely improved light interception, carbon assimilation and biomass accumulation, which ultimately translated into higher grain yield.

Effect of treatments on yield attributes and productivity

Improved growth parameters such as plant height, LAI, SPAD values and dry matter production may have enhanced assimilate production and translocation towards reproductive organs, thereby improving yield attributes and grain yield. Similar benefits of mulching were reported in improving grain weight due to better soil moisture conservation (7). Foliar-applied nutrients and bioactive compounds likely enhanced chlorophyll synthesis, enzymatic activity, N metabolism and photosynthetic efficiency, resulting in greater biomass accumulation and reproductive development. Superior physiological traits, such as higher LAI and SPAD values, may have contributed to enhance photosynthate translocation. Similar findings were previously reported in tomato and pepper (23) and in rice (8), where foliar application of fish-based organic formulations enhanced crop productivity. Although grain yield increased significantly under mulching and organic foliar spray treatments, harvest index, number of rows per cob and test weight remained non-significant. This suggests that the treatments primarily enhanced overall crop growth and dry matter accumulation rather than altering grain filling or biomass partitioning efficiency. Consequently, the increase in grain yield was mainly associated with greater biomass production, while individual

grain weight and harvest index remained relatively stable across treatments. Table 4 indicates that $M \times S$ interactions were non-significant for all yield attributes and yields. The absence of significant interaction effects suggests that the benefits of mulching and foliar organic formulations were largely independent and additive in nature.

Effect of treatments on cluster bean under intercropping

Improved performance of cluster bean under spread mulching may be associated with enhanced soil moisture conservation, increased nutrient availability, improved root proliferation and favourable conditions for rhizosphere microbial activity and biological N fixation. Organic nutrient sources likely promoted root growth and biological N fixation, resulting in better biomass accumulation and productivity. Higher performance under (3 % organic formulation (1 : 1 : 1) mixture of panchagavya, FEE and FFE) foliar treatment may be associated with rapid absorption of nutrients and growth-promoting substances supplied through panchagavya, FEE and FFE, which improved physiological activity and assimilate production. Similar findings were previously reported (11). Improved growth under organic nutrient management was also associated with greater microbial activity and soil fertility enhancement.

Correlation analysis

Correlation analysis revealed significant positive relationships among growth, physiological and yield parameters of maize under different organic nutrient, mulching and foliar treatments (Fig. 3) ($p < 0.001$). Plant height showed strong positive correlations with LAI ($r = 0.78$), SPAD value ($r = 0.70$), dry matter production ($r = 0.70$)

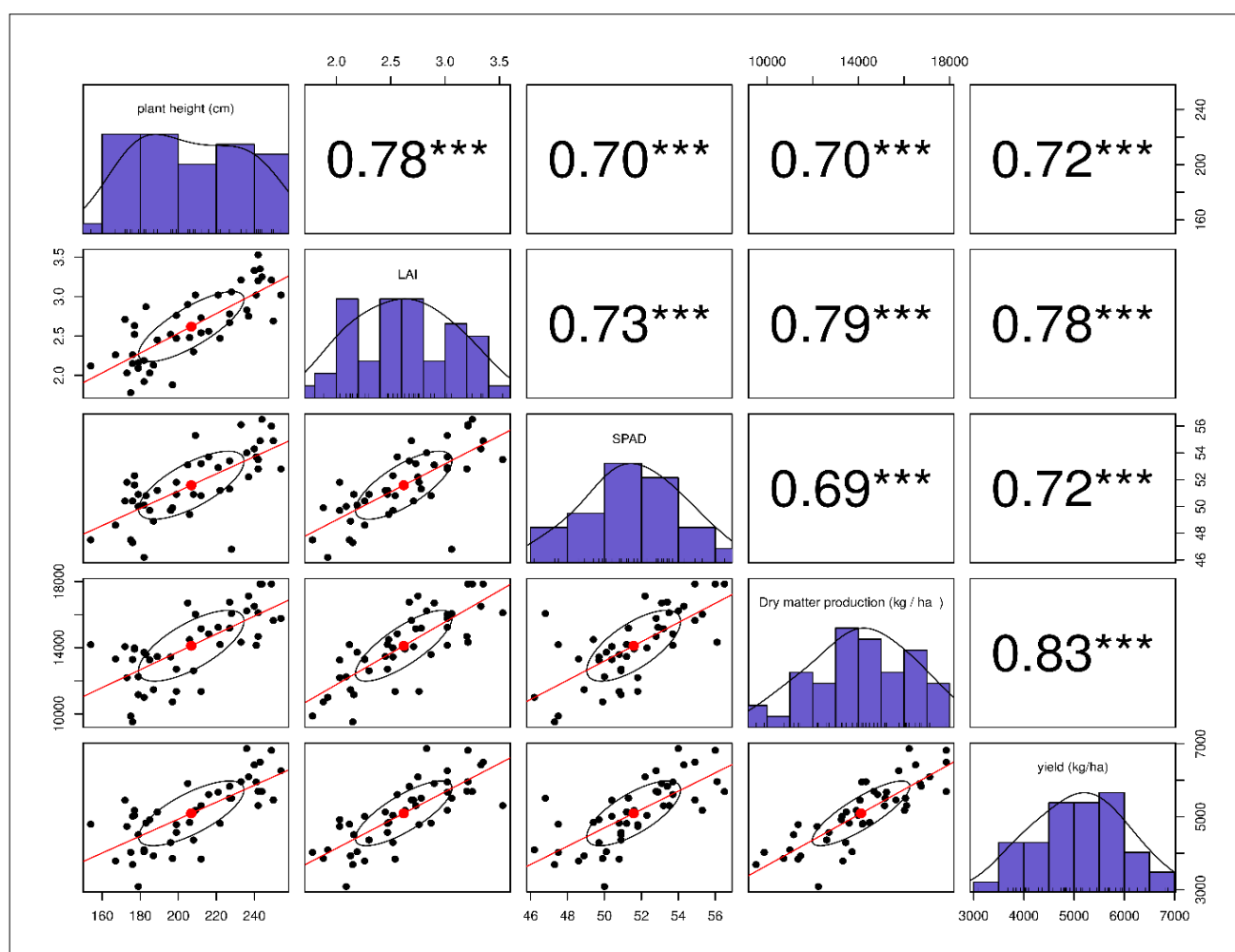


Fig. 3. Correlation among growth, physiological characteristics and productivity of maize.

and grain yield ($r = 0.72$), indicating that increased vegetative growth contributed to enhanced physiological efficiency and productivity. Leaf area index exhibited strong associations with SPAD ($r = 0.73$), dry matter production ($r = 0.79$) and grain yield ($r = 0.78$), suggesting that improved canopy development and photosynthetic surface area positively influenced biomass accumulation and yield. SPAD values were positively correlated with dry matter production ($r = 0.69$) and grain yield ($r = 0.72$), reflecting the importance of chlorophyll content and nutrient status in determining crop performance. Among all the relationships, dry matter production recorded the strongest positive correlation with grain yield ($r = 0.83$), indicating that greater biomass accumulation substantially contributed to higher yield. The correlation analysis confirms that improvements in canopy development, chlorophyll content and biomass accumulation were closely associated with increased grain yield, highlighting the effectiveness of integrated organic nutrient management in enhancing maize productivity.

Conclusion

In conclusion, the findings of this field experiment demonstrate that integrated organic nutrient management involving enriched vermicompost, humic acid and spread mulching (M_1) significantly improved growth parameters, physiological traits and yield of the maize + cluster bean intercropping system. The combined foliar application of Panchagavya, fermented egg extract (FEE) and fermented fish extract (FFE) produced the highest growth, chlorophyll content, biomass accumulation and yield among the evaluated foliar treatments. The combined application of organic nutrient sources, mulching and organic foliar sprays improved crop productivity through enhanced nutrient availability, moisture conservation and physiological efficiency. Spread mulching combined with enriched vermicompost and humic acid increased maize grain yield to 5508 kg ha^{-1} , while the combined organic foliar formulation achieved the highest grain yield of 6064 kg ha^{-1} . Similar improvements in growth and vegetable yield of cluster bean highlight the suitability of integrated organic management practices for enhancing the productivity of both component crops within the intercropping system. Therefore, this integrated approach can be considered a sustainable and effective strategy for improving productivity and maintaining soil health in maize-based intercropping systems. Future studies should evaluate long-term effects of these practices on soil biological properties, nutrient dynamics and system productivity under diverse agroecological.

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Authors' contributions

MV conceptualised and wrote the original draft. SPS conceptualised, supervised and reviewed writing and editing. PMS, KSB, EP contributed to the review the manuscript. All authors have read and approved the final manuscript.

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