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Waste to Resource: Utilizing Marigold Flower Liquid Biowaste for Maize Growth and Yield Enhancement

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Abstract

Agro-based industries generate large quantities of liquid and solid wastes, leading to environmental pollution and disposal challenges. Valorization of agro-industrial floral biowaste, particularly marigold flower liquid biowaste (MFLB), as a nutrient solution in agriculture offers a sustainable approach to waste management while reducing chemical fertilizer dependency. A field experiment was conducted during 2022-23 & 2023-24 at ZARS, GKVK, Bengaluru, to evaluate the effect of marigold flower liquid biowaste (MFLB) on growth, yield, nutrient uptake and economics in maize under a factorial randomized block design with 16 treatments replicated thrice. Treatments included plain and enriched MFLB, varied dosages with recommended nitrogen (RDN) and application at basal and tasselling stages. Results revealed that enriched MFLB and its integration with RDN (75:25) significantly enhanced the number of leaves, leaf area, SPAD readings, kernel and stover yields and nutrient uptake compared to sole MFLB application. The highest kernel (10,045 kg ha^{-1}) and stover yield (16,452 kg ha^{-1}) were recorded under 75% RDN + 25% MFLB, while sole MFLB application resulted in lower yields, indicating its limitation as a sole nutrient source. Economic analysis indicated higher net returns and favourable B:C ratios under integrated treatments compared to sole MFLB application. The study demonstrated that MFLB, particularly when enriched and integrated with inorganic fertilizers, can supplement nutrient requirements in maize, improving productivity and profitability while reducing environmental pollution and chemical fertilizer dependency. Adoption of MFLB under integrated nutrient management aligns with sustainable agricultural practices, supports circular bioeconomy and provides an environmentally friendly solution for managing agro-industrial floral biowaste. This approach effectively contributes to responsible waste utilization and sustainable maize production.

Keywords : Biowaste, Volarization, Marigold Flower Liquid Biowaste (MFLB), Photosynthetic potential, Lutein

Agro-based industries like sugar mills, rice mills, fruit and vegetable processing, distilleries and flower processing drive socio-economic growth in developing economies but generate substantial solid, liquid, and gaseous wastes (Singh and Agrawal, 2020). Liquid effluents feature high BOD, COD, suspended solids and nutrients, causing eutrophication, oxygen depletion and water contamination that harm aquatic life and health when discharged untreated (Mohan *et al.,* 2019 and Kumar *et al.,* 2021). Solid wastes (husks, bagasse, press mud, floral wastes) and air emissions (dust, CO_2, NO_x, SO_2) lead to soil/water pollution, odours, pests and climate impacts from poor management (Gupta & Pathak, 2019; Yadav *et al.,* 2022 and Sharma *et al.,* 2020).

Sustainable development and circular bioeconomy approaches promote biowaste valorisation into compost, biofertilizers, bioenergy (biogas, bioethanol) and nutrient solutions, cutting pollution while boosting soil fertility and productivity (Singh *et al.,* 2020; Kumar *et al.,* 2021 and Mohan *et al.,* 2019). Floral wastes (marigold, rose, temple) rich in organics can become biofertilizers, compost, pigments or oils instead of causing leachates and contamination (Yadav *et al.,* 2022 and Mishra *et al.,* 2022). These strategies support SDG 12 and SDG 13 by enhancing resource efficiency and curbing emissions (UN, 2021).

Marigold flowers are processed in agro-industries to extract lutein (for disease prevention in humans, used in food, medicine, feeds), xanthin (for functional foods and medicine) and oleoresin (for pharma, nutrition, dyes, pet industries); the process involves underground silo fermentation, screw pressing and generation of effluent stored in treatment plants. Marigold flowers, with 90 per cent moisture, yield 75-80 per cent water as biowaste during silage, dehydration and pressing-about 6 lakh liters from 25,000 metric tonnes - rich in lactic acid; adding calcium produces bioavailable calcium lactate, which promotes plant growth, hormone metabolism, phytic acid degradation and higher field bean yields without harming soil (Umashankar *et al.,* 2019). Proper treatment of this liquid biowaste offers broad agricultural potential.

Maize, known as the 'Queen of Cereals' for its high genetic yield potential, feeds over 900 million people in developing countries and serves multipurpose uses including human food, animal feed, fodder and industrial raw materials for starch, dextrose, oil, syrup, flakes, cosmetics, wax, alcohol and leather tanning (Murdia *et al.,* 2016). Globally, maize covers 193.7 million hectares across tropics with 114.7 million tonnes production at 5.75 t/ha productivity (Anonymous, 2020); updated projections show 2025/26 output reaching a record 1.265 billion metric tonnes, led by the USA (401.8 Mt, ~38%), China (295 Mt), Brazil (131 Mt), EU (60 Mt), Argentina (53 Mt) and others. In India, third after rice and wheat, maize occupies 82 per cent Kharif area in states like Karnataka (9.86 m ha, 32.42 m t, 34.51% national share), Andhra Pradesh, Madhya Pradesh, Maharashtra, Rajasthan (Anonymous, 2020). This study explores using marigold flower liquid biowaste as a sustainable nutrient solution for maize, boosting productivity while managing agro-industrial waste and curbing pollution.

MATERIAL AND METHODS

Field experiment was conducted during 2022-23 & 2023-24 at the Agronomy field unit, Zonal Agricultural Research Station, UAS, GKVK, Bengaluru. It is situated in Eastern Dry Zone (Agro-Climatic Zone V) of Karnataka at a latitude of 12^0 58' North, longitude of 77^0 33' East and an altitude of 930 m above the mean sea level. The soils at GKVK farm belong to the Vijayapura series, classified as Oxichaplustalf (USDA) or ferric luvisols (FAO), consisting of reddish-brown lateritic types derived from gneiss in a subtropical semi-arid climate. These deep, well-drained, moisture-retentive soils exhibit red sandy loam texture at the surface, transitioning to finer red sandy clay loam with depth; particle composition includes 35.3 per cent coarse sand, 28.9 per cent fine sand, 6.58 per cent silt and 28.8 per cent clay. The site features uniform topography, slightly acidic pH (6.7), low electrical conductivity (0.21 dS m^{-1}) and medium fertility: 0.65 per cent organic carbon, 289.4 kg ha^{-1} available N, 28.6 kg ha^{-1} P, and 235.2 kg ha^{-1} K. Experiment was conducted with Randomized complete block design with factorial concept with three factors: Factor-1: Marigold flower liquid biowaste, Factor-2: Dosage of marigold flower liquid biowaste and Factor-3: Application at different stages *i.e.,* Basal application and Application at basal and tasselling stage that includes 16 treatments with three replications. Marigold flower liquid biowaste was collected from a marigold flower processing industry located at Harapanahalli, Vijayanagar district Karnataka, India in clean plastic containers after preliminary analysis. Marigold flower liquid biowaste was treated with calcium oxide (CaO) at the rate of

1.6 g L^{-1} of liquid biowaste and enriched with plant growth promoting microorganisms (PGPM) at 10 per cent and humic substance at 75 L ha^{-1} before 10 days of soil application. The growth parameters like number of leaves per plant, leaf area per plant and SPAD values were recorded by using standard methods of five plants that were randomly selected in each treatment at 30, 60, 90 DAS and at harvest. The grain yield and stover yield obtained from the net plot area was converted into yield per unit area. Total nutrient uptake of the plant sample was estimated by adopting the standard method by Piper (1966). The experimental data collected on growth and yield components; total nutrient uptake of plants and economics were subjected to Fisher's method of 'Analysis of Variance' (ANOVA). All the data were analysed and the results were presented and discussed at a probability level of five per cent.

RESULTS AND DISCUSSION

Number of Leaves

The application of marigold flower liquid biowaste (MFLB) and its enriched formulation significantly influenced the number of leaves in maize at 60 and 90 DAS (Table 1), while no significant differences were observed at 30 DAS. Enriched MFLB (E2) recorded a higher number of leaves (12.62 pooled) at 60 DAS compared to MFLB (E1) (11.95 pooled). At 90 DAS, E2 (11.87 pooled) maintained slightly higher leaf numbers than E1 (11.62 pooled). Among the dosages, F1 (75:25, RDN: MFLB) recorded the highest number of leaves at 60 DAS (12.65 pooled) and 90 DAS (11.88 pooled), followed by F2 (50:50) and F3 (25:50). The lowest leaf count was observed with F4 (only MFLB) at 60 DAS (11.65 pooled) and 90 DAS (11.61 pooled).

TABLE 1

Effect of marigold flower liquid biowaste on number of leaves of maize

Treatments	30 DAS			60 DAS			90 DAS		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Marigold flower liquid biowaste (MFLB)									
E_1 - MFLB	6.38	6.16	6.39	11.83	12.82	11.95	11.61	11.62	11.62
E_2 - Enriched MFLB	6.20	6.40	6.18	12.42	12.08	12.62	11.91	11.86	11.87
S.Em. ±	0.07	0.02	0.04	0.17	0.05	0.10	0.06	0.05	0.04
CD (5%)	NS	NS	NS	0.48	0.14	0.29	0.18	0.15	0.12
Dosage of Marigold flower liquid biowaste									
F_1 - (75:25 - RDN:MFLB)	6.53	6.38	6.46	12.72	12.58	12.65	11.87	11.88	11.88
F_2 - (50:50 - RDN: MFLB)	6.53	6.41	6.40	12.50	12.54	12.52	11.70	11.81	11.79
F_3 - (25:50 - RDN: MFLB)	6.32	6.42	6.37	12.00	12.63	12.32	11.78	11.68	11.70
F_4 - (Only MFLB)	5.92	5.91	5.91	11.27	12.04	11.65	11.68	11.59	11.61
S.Em.±	0.10	0.02	0.05	0.23	0.07	0.14	0.09	0.07	0.06
CD (5%)	NS	NS	NS	0.67	0.20	0.40	0.26	0.21	0.17
Application at different stages									
G_1 - Basal Application	6.38	6.29	6.23	11.95	12.27	12.11	11.69	11.69	11.69
G_2 - Basal and Tassel	6.20	6.26	6.33	12.29	12.83	12.46	11.83	11.79	11.80
S.Em.±	0.07	0.02	0.04	0.17	0.05	0.10	0.06	0.05	0.04
CD (5%)	NS	NS	NS	0.48	0.14	0.29	0.18	0.15	0.13

Basal and tassel stage application (G2) resulted in significantly higher leaf numbers (12.46 pooled) at 60 DAS compared to basal application alone (G1, 12.11 pooled). A similar trend was observed at 90 DAS, with G2 recording 11.80 leaves versus 11.69 under G1. The findings indicate that marigold flower liquid biowaste, especially in its enriched form and when combined with recommended nitrogen doses, can enhance the number of leaves in maize, thereby improving the photosynthetic potential of the crop (Savitha and Srinivasamurthy, 2015). The significant improvement in leaf number with enriched MFLB (E2) may be attributed to enhanced nutrient availability, improved microbial activity and increased nitrogen mineralization, which collectively support better vegetative growth (Patil *et al.,* 2017). Enrichment likely increases the availability of macro and micronutrients, which are critical for leaf initiation and expansion (Choudhary *et al.,* 2014). The combination of RDN and MFLB at 75:25 (F1) resulted in the highest leaf count, suggesting that integrated nutrient management with a higher proportion of inorganic nitrogen alongside organic liquid biowaste supports rapid vegetative growth while maintaining soil health (Kumar *et al.,* 2018). This synergistic approach aligns with the nutrient uptake pattern of maize, where peak nitrogen demand coincides with active vegetative growth. Application at basal and tassel stages (G2) further improved leaf numbers, indicating the importance of supplemental nutrient supply during the tasselling stage, which supports sustained leaf health and delays senescence (Singh *et al.,* 2020). This is crucial as leaf area index during reproductive stages significantly contributes to photosynthate supply for grain filling (Sangakkara *et al.,* 2004). The absence of significant differences at 30 DAS suggests that the positive effects of MFLB are more pronounced from 60 DAS onwards, aligning with the active nutrient uptake and rapid leaf development phase in maize.

Leaf Area Per Plant (cm²)

The application of Marigold Flower Liquid Biowaste (MFLB) and its enriched form significantly influenced the leaf area of maize at different growth stages. At 30 DAS, pooled leaf area ranged from 816 cm² (F4: Only MFLB) to 1208 cm² (F1: 75:25 RDN:MFLB). At 60 DAS, leaf area ranged from 4990 cm² (F4) to 7099 cm² (F1). At 90 DAS, leaf area was highest in F1 (6989 cm²), followed by F2 and F3, while the lowest was in F4 (4959 cm²). At harvest, leaf area followed a similar trend, with F1 showing maximum pooled value (5798 cm²) and F4 the minimum (4300 cm²). Between E1 (MFLB) and E2 (enriched MFLB), E2 recorded higher leaf area at 90 DAS (6058 cm²) and at harvest (5215 cm²) than E1 (5811 and 5090 cm², respectively), indicating the positive effect of enrichment. Regarding application stage, G1 (Basal) and G2 (Basal + Tassel) did not show significant differences, indicating that a single basal application was adequate under the present conditions (Table 2). The increase in leaf area with enriched MFLB (E2) over plain MFLB (E1) can be attributed to the additional availability of nutrients in the enriched biowaste, which would have provided readily available macro- and micronutrients for the crop, enhancing cell expansion and leaf development (Yadav *et al.,* 2020). Leaf area is a critical determinant of the photosynthetic capacity of the plant, directly affecting the biomass accumulation and productivity of maize (Tollenaar and Lee, 2006). The superiority of F1 (75:25 RDN:MFLB) in all stages suggests that while MFLB supplies organic nutrients and growth-promoting substances, the partial application of recommended nitrogen dose is essential to meet the immediate N requirement of maize, which is crucial during early growth stages for leaf expansion (Singh *et al.,* 2012). The lower leaf area under F4 (100% MFLB without RDN) indicates that MFLB alone cannot fully substitute inorganic N for optimal leaf area development, likely due to slower mineralization and lower immediate N availability (Ghosh and Bandopadhay, 2019). Interestingly, the application timing (Basal vs Basal + Tassel) did not significantly influence the leaf area, which aligns with observations by Sharma *et al.* (2021), suggesting that the nutrient availability during early growth stages is more critical for leaf area development in maize than split applications at tassel initiation.

TABLE 2
Effect of marigold flower liquid biowaste on leaf area (cm^2) of maize

Treatments	30 DAS			60 DAS			90 DAS			At Harvest		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Marigold flower liquid biowaste (MFLB)												
E_1 - MFLB	1060	1027	1043	5974	5984	5979	5809	5814	5811	5088	5092	5090
E_2 - Enriched MFLB	1012	1025	1019	5960	5965	5963	6049	6067	6058	5215	5216	5215
S.Em. ±	27.49	0.81	13.89	3.19	18.86	9.66	1.03	0.90	0.80	0.81	3.05	1.71
CD (5%)	NS	NS	45.64	9.16	56.45	NS	2.95	2.59	2.28	2.31	8.75	4.92
Dosage of Marigold flower liquid biowaste												
F_1 - (75:25 - RDN : MFLB)	1204	1212	1208	7097	7102	7099	6975	7004	6989	5795	5801	5798
F_2 - (50:50 - RDN : MFLB)	1042	1052	1047	6091	6098	6095	6104	6111	6108	5201	5204	5202
F_3 -(25:50 - RDN : MFLB)	1093	1012	1053	5695	5702	5699	5678	5685	5682	5309	5312	5311
F_4 - (Only MFLB)	805.67	827.75	816.71	4984	4996	4990	4957	4962	4959	4301	4299	4300
S.Em. ±	38.88	1.14	19.65	4.51	26.68	13.66	1.45	1.27	1.13	1.14	4.31	2.42
CD (5%)	111.62	3.27	56.41	12.96	76.59	39.21	4.18	3.66	3.23	3.27	12.37	6.96
Application at different stages												
G_1 - Basal Application	1039	1008	1023	5948	5960	5954	5892	5908	5900	5164	5165	5165
G_2 - Basal and Tassel	1033	1044	1039	5985	5990	5987	5965	5973	5969	5139	5143	5141
S.Em. ±	27.49	0.81	14.02	3.19	18.45	9.66	1.03	0.90	0.80	0.81	3.05	1.71
CD (5%)	78.93	2.31	43.46	9.16	55.21	27.73	2.95	2.88	2.28	2.31	8.75	4.92

These findings are consistent with previous reports indicating that the application of liquid organic biowaste can enhance leaf area and biomass in maize when combined with inorganic fertilizers (Dwivedi *et al.,* 2014), as the organic fraction improves soil microbial activity and nutrient release patterns while inorganic N ensures immediate nutrient availability for rapid vegetative growth (Saha *et al.,* 2021).

SPAD Readings

SPAD values correlate strongly with chlorophyll and nitrogen content in leaves (Uddin *et al.,* 2013). The higher SPAD readings under enriched MFLB (E2) indicate better N mineralization and nutrient supply compared to plain MFLB, supporting effective chlorophyll synthesis and leaf greenness (Saha *et al.,* 2021). The superiority of F1 dosage (75:25 RDN:MFLB) in maintaining higher SPAD values at all growth stages indicates the importance of integrated nutrient management, where partial substitution of inorganic N with organic liquid biowaste supplies immediate N (via RDN) and sustained N and micronutrients (via MFLB) (Dwivedi *et al.,* 2014). This finding aligns with Singh *et al*. (2012), who reported improved nitrogen uptake and chlorophyll content with integrated N management in maize. The lower SPAD values under F4 (100% MFLB) across all stages reflect insufficient immediate N availability, limiting chlorophyll synthesis, consistent with reports by Ghosh *et al*. (2019) on slow N mineralization from organic sources (Table 3). The slight improvement in SPAD with split application (Basal + Tassel) indicates better nitrogen availability during critical stages of reproductive development, helping to sustain chlorophyll levels (Sharma *et al*., 2021). However, the differences, while statistically significant in some stages, are operationally small, suggesting flexibility in adopting either method depending on labour and operational convenience.

Grain Yield and Stover Yield

The application of marigold flower liquid biowaste (MFLB) and its enriched formulations significantly influenced kernel and stover yield in maize across two consecutive years and pooled analysis (Fig. 1). Enriched MFLB (E2) recorded higher kernel yield (8849 kg/ha pooled) compared to MFLB (E1) (8750 kg/ha pooled). Similarly, E2 produced a slightly higher stover yield (14306 kg/ha pooled) compared to E1 (14245 kg/ha pooled). Although E2 (Enriched MFLB) showed numerically higher kernel and stover yields, differences were statistically non-significant, suggesting enrichment marginally improves nutrient availability and mineralization (Sanam *et al.,* 2022), supporting consistent plant growth without large yield differences under similar nutrient environments. Dosage treatments revealed significant differences in kernel and stover yield. F1 (75:25, RDN:MFLB) recorded the highest kernel yield (10045 kg/ha pooled) and stover yield (16452 kg/ha pooled). This was followed by F2 (50:50), which recorded 9616 kg/ha kernel yield and 15576 kg/ha stover yield. F3 (25:50) recorded moderate yields (8292 kg/ha kernel, 13488 kg/ha stover). The lowest yields were observed in F4 (only MFLB) with kernel yield of 7245 kg/ha and stover yield of 11586 kg/ha. Higher proportion of RDN ensures immediate nitrogen availability for crop uptake, while MFLB provides slow-release nutrients and improves soil microbial activity and structure (Singh *et al*., 2020). The decrease in yields with increasing MFLB proportion (F2 to F4) demonstrates that exclusive reliance on organic liquid biowaste may not meet the immediate nitrogen demand of high-yielding maize, consistent with nutrient demand patterns in maize. These results are in agreement with Verma *et al*. (2019), who reported higher grain and stover yields in maize under integrated nutrient application over sole organic treatments. Basal and tassel stage application (G2) produced slightly higher kernel (8817 kg/ha pooled) and stover yield (14311 kg/ha pooled) than basal alone (G1) (8782 kg/ha kernel, 14240 kg/ha stover). The differences were within the critical difference, indicating non-significance statistically. Additional application during tasselling supports nutrient availability during reproductive stages, critical for grain filling and stover biomass (Singh *et al*., 2020).

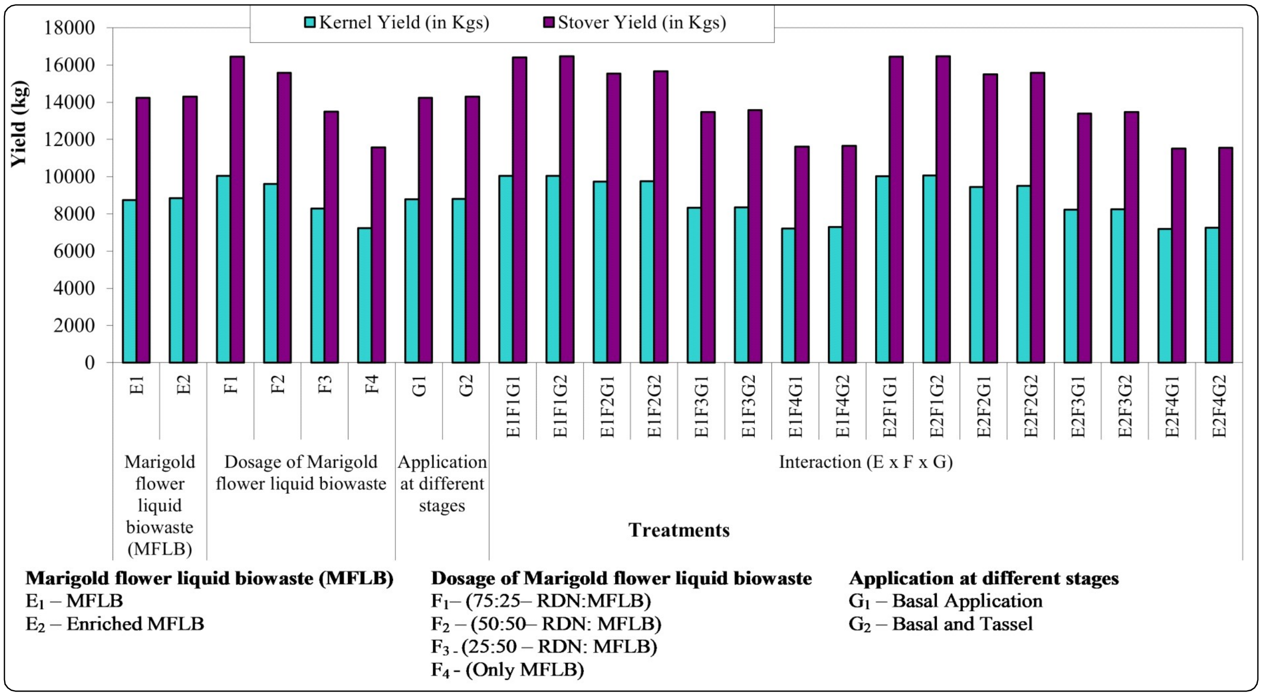

Fig. 1 : Effect of marigold flower liquid biowaste on kernel yield and stover yield of maize

However, the marginal differences indicate that a single basal application may also be adequate under moderate nutrient management, with additional tassel-stage application serving as a yield stabilizer under varied environmental conditions.

Total Nutrient Uptake

The results indicated a significant influence of the dosage of marigold flower liquid biowaste (MFLB) on total N, P and K uptake in maize. Among the MFLB types, enriched MFLB (E2) recorded slightly higher N, P and K uptake compared to MFLB alone (E1), but the differences were statistically non-significant (Table 4). Among the dosage treatments, the F1 treatment (75:25 RDN: MFLB) recorded the highest total nutrient uptake with pooled N (210.49 kg ha^{-1}), P (29.91 kg ha^{-1}) and K (224.14 kg ha^{-1}). This was significantly higher than F4 (only MFLB), which recorded the lowest nutrient uptake (N: 111.46 kg ha^{-1}; P: 21.49 kg ha^{-1}; K: 144.67 kg ha^{-1}). Regarding application stages, basal plus tassel application (G2) recorded marginally higher N, P and K uptake than basal alone (G1), but differences were not statistically significant. The results revealed that partial substitution of RDN with MFLB (75:25) resulted in higher nutrient uptake, indicating that integrating organic sources with inorganic fertilizers enhances nutrient availability and uptake efficiency. Enhanced mineralization of organic N from MFLB under the presence of inorganic N, improving synchronization of nutrient release and crop demand (Sharma, 2018). Organic acids and phytohormones in MFLB may aid in better P solubilization and K mobilization (Kumar, 2020). The improved microbial activity due to MFLB application may contribute to better nutrient cycling and root proliferation, enhancing nutrient absorption (Ramachandran, 2021). The lower nutrient uptake under only MFLB (F4) confirms that organic liquid biowaste alone is insufficient to meet the nutrient demands of a high nutrient-extractive crop like maize, aligning with findings by Yadav *et al.* (2019). The non-significant but positive trend with tassel stage application suggests marginal benefits in extending nutrient availability during the reproductive phase, but the primary requirement remains during the vegetative stage. These findings underscore the potential of marigold flower liquid

TABLE 4
Effect of marigold flower liquid biowaste on uptake of nutrients of maize

Treatments	N (kg ha^{-1})			P (kg ha^{-1})			K (kg ha^{-1})		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
Marigold flower liquid biowaste (MFLB)									
E$_1$ - MFLB	187.14	176.34	175.37	25.75	27.07	26.28	189.25	192.83	189.75
E$_2$ - Enriched MFLB	189.28	177.39	175.80	26.11	27.43	26.77	187.14	192.36	190.59
S.Em. ±	0.41	1.10	0.41	0.26	0.30	0.40	0.41	0.40	0.42
CD (5%)	1.17	3.23	1.35	1.02	0.95	1.28	1.17	1.33	1.47
Dosage of Marigold flower liquid biowaste									
F$_1$ - (75:25 - RDN:MFLB)	221.34	212.78	210.49	29.56	30.72	29.91	221.34	228.20	224.14
F$_2$ - (50:50 - RDN: MFLB)	203.54	201.02	199.66	27.06	29.41	28.17	203.54	203.73	203.70
F$_3$ - (25:50 - RDN: MFLB)	185.72	181.22	180.74	26.11	27.22	26.54	185.72	190.98	188.17
F$_4$ - (Only MFLB)	142.19	112.45	111.46	21.00	21.64	21.49	142.19	147.47	144.67
S.Em.±	0.58	1.55	0.58	0.37	0.43	0.57	0.58	0.56	0.60
CD (5%)	1.66	4.46	1.66	1.05	1.23	1.64	1.66	1.61	1.72
Application at different stages									
G$_1$ - Basal Application	185.10	175.69	175.23	25.96	26.86	26.42	185.10	190.83	187.81
G$_2$ - Basal and Tassel	191.30	178.05	175.94	25.91	27.64	26.64	191.30	194.36	192.53
S.Em.±	0.41	1.10	0.41	0.28	0.30	0.40	0.41	0.40	0.42
CD (5%)	1.17	3.16	1.14	1.33	0.98	1.23	1.7	1.14	1.21

biowaste as a supplementary source of nutrients in an integrated nutrient management strategy for sustainable maize production while reducing chemical fertilizer dependency.

The economic analysis indicated substantial variation in cost of cultivation, gross returns, net returns and B:C ratio under different MFLB-based treatments in maize (Table 5). Gross returns were highest under T17 (RDF + FYM) with Rs.182,070 ha^{-1} (2023) and Rs.181,062 ha^{-1} (2024), followed closely by T10 (75% RDN + 25% MFLB EME B&T) and T1 (75% RDN + 25% MFLB TME). Net returns were highest in T17 (Rs.138,498 ha^{-1} in 2023, Rs.137,490 ha^{-1} in 2024), followed by T1 and T10, while the lowest net returns were recorded in T16 (Rs.86,732-Rs.86,750 ha^{-1}) and T8 (Rs.87,380-Rs.87,506 ha^{-1}. The B:C ratio was maximum under the absolute control (T18) (4.556 in 2023, 4.562 in 2024) due to the very low cost of cultivation despite lower yields, followed closely by T1 and T17 (4.15-4.17). Sole MFLB application treatments (T7, T8, T15, T16) consistently recorded lower B:C ratios (~3.0) and net returns compared to integrated treatments.

Treatments combining 75% RDN + 25% MFLB (T1, T10) and RDF + FYM (T17) resulted in higher gross and net returns and favourable B:C ratios, confirming the economic viability of partial substitution of chemical fertilizers with MFLB. These findings align with Das *et al.* (2022), who reported that combining organic sources with inorganic fertilizers enhances productivity and profitability in maize while maintaining soil health. Treatments with 100% N supplied through MFLB alone (T7, T8, T15, T16) exhibited the lowest net returns and

TABLE 5
Effect of marigold flower liquid biowaste on economics of maize

Treatments	Cost of cultivation (Rs.)	Gross Returns (Rs.)		Net Returns (Rs.)		B:C ratio	
		2023	2024	2023	2024	2023	2024
T_1 - 75% N through RDN + marigold flower liquid biowaste equivalent to 25 % N (TME)	43223	180630	180864	137407	137641	4.17	4.18
T_2 - 75% N through RDN + marigold flower liquidbiowaste equivalent to 25 % N (EME)	43510	180648	180738	137138	137228	4.15	4.15
T_3 - 50% N through RDN + marigold flower liquid biowaste equivalent to 50 % N (TME)	42871	175320	175464	132449	132593	4.08	4.09
T_4 - 50% N through RDN + marigold flower liquid biowaste equivalent to 50 % N (EME)	43446	175770	175734	132324	132288	4.04	4.04
T_5 - 25% N through RDN + marigold flower liquid biowaste equivalent to 75 % N (TME)	42521	150030	150138	107509	107617	3.52	3.53
T_6 - 25% N through RDN + marigold flower liquid biowaste equivalent to 75 % N (EME)	43384	150264	150336	106880	106952	3.46	3.46
T_7 - 100% N through marigold flower liquidbiowaste only (TME)	42690	130032	130122	87342	87432	3.04	3.04
T_8 - 100% N through marigold flower liquid biowaste only (EME)	43840	131220	131346	87380	87506	2.99	2.99
T_9 - 75% N through RDN + marigold flower liquid biowaste equivalent to 25 % N (TME) (B&T)	43223	180432	180540	137209	137317	4.17	4.17
T_{10}-75% N through RDN + marigold flower liquid biowaste equivalent to 25 % N (EME) (B&T)	43510	181314	181404	137804	137894	4.16	4.16
T_{11}- 50% N through RDN + marigold flower liquid biowaste equivalent to 50 % N (TME) (B&T)	42871	170046	170028	127175	127157	3.96	3.96
T_{12}- 50% N through RDN + marigold flower liquid biowaste equivalent to 50 % N (EME) (B&T)	43446	171054	171234	127608	127788	3.93	3.94
T_{13} - 25% N through RDN + marigold flower liquid biowaste equivalent to 75 % N (TME) (B&T)	42521	148032	148032	105511	105511	3.48	3.48
T_{14} - 25% N through RDN + marigold flower liquid biowaste equivalent to 75 % N (EME) (B&T)	43384	148608	148626	105224	105242	3.42	3.42

Continued....

TABLE 5 Continued....

Treatments	Cost of cultivation (Rs.)	Gross Returns (Rs.)		Net Returns (Rs.)		B:C ratio	
		2023	2024	2023	2024	2023	2024
T_{15}- 100% N through marigold flower liquid biowaste only (TME) (B&T)	42690	129618	129816	86928	87126.2	3.03	3.04
T_{16}- 100% N through marigold flower liquid biowaste only (EME) (B&T)	43840	130572	130590	86732	86750	2.97	2.97
T_{17} - RDF + FYM	43572	182070	181062	138498	137490	4.17	4.15
T_{18} - Absolute control	22772	103752	103878	80980	81106	4.55	4.56

B:C ratios (~3.0), indicating that MFLB alone cannot meet the nutrient demands of maize economically, which agrees with Yadav *et al.* (2019), who noted limitations of liquid biofertilizers in sustaining yields when used as the sole nutrient source. The application of MFLB at basal + tasselling stages showed slight improvements in gross and net returns, indicating better nutrient availability and uptake during critical growth stages but did not lead to significant differences in the B:C ratio. Although the absolute control had the highest B:C ratio due to minimal input costs, the gross and net returns were the lowest, emphasizing that B:C ratio alone should not be the sole metric and profitability and productivity should also guide nutrient management decisions.

The study demonstrated that marigold flower liquid biowaste (MFLB), particularly when enriched, can effectively supplement recommended nitrogen doses in maize cultivation, improving growth, yield, nutrient uptake and profitability. Treatments combining 75 per cent recommended nitrogen (RDN) with 25% MFLB (both enriched and plain) recorded the highest kernel and stover yields, nutrient uptake and net returns with favourable B:C ratios, highlighting the benefits of integrated nutrient management for sustainable maize production. Sole application of MFLB, despite its environmental advantages, was insufficient to meet the high nutrient demands of maize, resulting in lower yields and economic returns. Enrichment of MFLB marginally improved nutrient availability and yield parameters but did not lead to significant differences in economic returns under similar conditions. Application timing at basal and tasselling stages provided slight benefits in yield and nutrient uptake, ensuring nutrient availability during critical growth stages. The study under scores the potential of valorising agro-industrial floral biowaste as a nutrient source in crop production, reducing environmental pollution, supporting circular bioeconomy and reducing chemical fertilizer dependency while maintaining profitability in maize cultivation. Adoption of MFLB in integrated nutrient management aligns with sustainable agriculture goals while managing agro-industrial waste responsibly.

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