

Organic Inputs for Climate-Smart Agriculture: Effects of Sunflower (*Tithonia diversifolia*) Leaf Residues and Extracts on Tomato (*Lycopersicum esculentum* Mill.) Yield and Soil Nutrient Dynamics

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Tomato (*Solanum lycopersicum* L.), a widely cultivated and consumed vegetable crops worldwide, was an object of a field trial for two seasons [early (rainy) and late (dry)] seasons, 2023–2024 at NIHORT, Ibadan to evaluate sunflower (*Tithonia diversifolia*) based organic inputs for tomato (*Solanum lycopersicum* L.) production. Using a 2×5 factorial RCBD with three replicates, treatments combined four rates of sun-dried sunflower compost (0, 1, 2, 3 t ha⁻¹) and three foliar spray rates of sunflower leaf compost extract (0; 1,000; 2,000 dm³ ha⁻¹). The dry leaves were incorporated two weeks before transplant, while the compost extracts were applied at four and six weeks after transplant. During the 2023 season, the application of 3 t ha⁻¹ of leaves compost increased early-season fresh fruit weight from 724.5 to 1,045.5 kg ha⁻¹ and late-season weight from 280.0 to 818.0 kg ha⁻¹. The foliar compost extract at 2 000 dm³ ha⁻¹ raised fresh yield from 831.5 to 907.0 kg ha⁻¹ and fruit number per plant from 146.0 to 200.5. while the 2024 season, 3 t ha⁻¹ of leaf compost boosted early-season yield from 64.0 to 333.0 kg ha⁻¹ and fruit count per plot from 28 to 316, while compost extract increased fresh yield from 832.0 to 907.0 kg ha⁻¹. All main effects were significant ($p \leq 0.05$); while there was no significance in the interactions. This discovery demonstrated that 3 t ha⁻¹ of dry sunflower leaf compost substantially enhanced the tomato growth and yield, and that 3 000 dm³ ha⁻¹ of leaf compost extract provides additional biostimulant benefits. Hence the incorporation of sunflower compost biomass and fresh extracts offered a low-cost, sustainable alternative to synthetic fertilizers, therefore, advancing climate-smart tomato production in tropical agroecosystems, while further research is needed in other area of climate smart agriculture.

Keywords: *Tithonia diversifolia*, organic amendment, leaf extract, tomato yield, biostimulant, tropical agriculture

1 Introduction

Tomato (*Solanum lycopersicum* L.) is among the most widely cultivated and consumed vegetable crops globally. It is highly valued for its edible fruits, rich in essential nutrients including vitamins A, C, E, and K, minerals, amino acids, dietary fibre, and the antioxidant lycopene, which has been linked to reduced risks of chronic diseases in humans (Kumar et al., 2022, Ali et al., 2020). As a member of the Solanaceae family, tomato ranks second only to potato in global importance among vegetable crops (Liu et al., 2022), contributing significantly to food security, nutrition, and rural livelihoods across both developed

and developing countries, particularly in Africa (Gerakari et al., 2024). Globally, tomato production reached approximately 189 million tonnes in 2021, cultivated on over 5 million hectares of land, with significant demand in fresh and processed forms including sauces, purées, and pastes (FAO, 2022). In Africa, Nigeria stands out as a major producer, with over 2.5 million tonnes produced annually (FAOSTAT, 2022), especially in key northern states such as Kano, Kaduna, Gombe, Bauchi, and Plateau (Ajenifujah-Solebo et al., 2025). The availability of irrigation has enabled year-round cultivation across Nigeria's agro-ecological zones, allowing both rainy

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and dry season production cycles (Abolosuro et al., 2014). However, tomato production in Nigeria faces critical sustainability challenges. The rising costs of chemical inputs, particularly fungicides and synthetic fertilizers such as NPK, along with the environmental risks of groundwater contamination, greenhouse gas emissions, and soil degradation, have raised concerns (Amirahmadi et al., 2023; Govindasamy et al., 2023; Abbasi & Khaliq, 2016). Moreover, climate change has compounded these threats, disrupting farming systems and threatening long-term viability (Amirahmadi et al., 2023; Zhao et al., 2025). This calls for the adoption of more sustainable, climate-resilient practices in line with global efforts toward nature-positive agriculture and resilient agri-food systems (Kaushal et al., 2025; FAO, 2023). To support this transition, organic fertilizers derived from plant biomass are increasingly recommended. These inputs promote slow nutrient release, improve soil organic matter, and enhance microbial biodiversity, all of which are crucial for sustaining soil health and crop productivity (Li et al., 2021; Abbasi & Khizar, 2012; Sagnon et al., 2024; Abdelaziz et al., 2007; Ali et al., 2014; Adnyana et al., 2025). Among plant-based bioresources, *Tithonia diversifolia* (Mexican sunflower) has gained prominence for its high nitrogen content, rapid decomposition, and adaptability across various ecological zones (Sembiring & Banjarnahor, 2024; Jama et al., 2000; Sparta et al., 2025). Native to Central America but now widespread in tropical West Africa, *T. diversifolia* has been dubbed the “miracle plant” due to its agronomic, medicinal, and ecological benefits (Omokhua et al., 2018). Recent studies suggest that compost derived from *T. diversifolia* can enhance crop growth, soil fertility, and nutrient availability (Sembiring & Banjarnahor, 2024; Jama et al., 2000; Sparta et al., 2025; Zen El-Dein, 2024; Durmuş & Kızılkaya, 2022). Additionally, its use in intercropping and integrated nutrient management systems has shown potential for boosting yields while reducing chemical inputs (Zen El-Dein, 2024; Kooshki et al., 2024; Srivastava et al., 2024). Yet, empirical data on its performance as a composted fertilizer for high-value vegetable crops like tomato remains limited. Consequently, this study seeks to experimentally evaluate the effects of different application rates of dry and fresh *T. diversifolia* compost on the agronomic and yield performance of tomato plants under field conditions. (Govindasamy et al., 2023; Abbasi & Khizar, 2012; Abbasi & Khaliq, 2016; Sagnon et al., 2024) This research aims to determine optimal compost rates for maximum tomato yield under the *T. diversifolia* compost treatments with animal compost and untreated controls, while promoting environmental integrity and soil sustainability (Bai et al., 2024; Abdelaziz et al., 2007; Ali et al., 2014; Kooshki et al., 2024; Ali et al., 2020; Rupngam et al., 2025). The findings are expected to contribute

to the broader goals of sustainable agriculture, climate-smart farming, and food system resilience in sub-Saharan Africa and beyond.

2 Materials and Methods

2.1 Nursery Establishment

The certified, disease-free seeds of tomato (*Solanum lycopersicum*) were procured from the Vegetable Seed Unit of the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria and the seeds were sown into sterilized sandy-loam soil contained in plastic trays under a screen house environment. The seedlings were irrigated regularly and monitored for pests and disease incidence and severity. After three weeks of healthy growth, the healthy seedlings were transplanted to the field.

2.2 Experimental Site Description

The field trials were conducted at the NIHORT Research Farm, Idi-Ishin Ibadan (Latitude 7° 24'–7° 36' N, Longitude 3° 50'–3° 49' E) within the rainforest–savannah transitional agro-ecological zone of southwestern Nigeria. The experimental site experiences bimodal rainfall distribution with an annual mean of approximately 1,200–2,500 mm, characterized as sandy-loam soil which is ideal for vegetable cultivation. The field experiments were conducted during the early and late rainy seasons of 2023 and dry season repeated in 2024. The land preparation and experimental design was on an experimental field (37 × 8 m; 296 m²), manually cleared, ploughed, and harrowed to achieve a fine bed cultivation. The experimental field was divided into plots measuring 2 × 1 m, and separated by 0.5 m within blocks and 1 m between replicates. The study employed a 2 × 5 factorial arrangement in a Randomized Complete Block Design (RCBD) with three replications. The treatment factors were: dry Sunflower leaves (*Tithonia diversifolia*) compost applied at 0, 1, 2, and 3 t ha⁻¹ fresh sunflower leaf compost extract applied as a foliar spray at 0, 1,000, and 2,000 l ha⁻¹. This combination produced 10 treatments in total. Dry sunflower compost leaves were incorporated into the soil two weeks before transplanting to facilitate the decomposition of the organic matter and nutrient release. The tomato seedlings were transplanted at a spacing of 50 × 20 cm, two seedling per stand. Soil sampling analysis prior to treatment application was carried out as composite soil samples (0–20 cm depth) were collected from five random locations across the experimental field. The soil samples were air-dried, sieved through a 2 mm mesh, and analysed to determine baseline soil properties at the Land and Water Unit of I.A.R and T Moore Plantation Ibadan, including: Soil pH (in water, 1 : 2.5 w/v), Organic carbon (Walkley-Black wet oxidation method), Total nitrogen (Kjeldahl method), Available

phosphorus (Bray-1 extraction method), Exchangeable bases (K^+ , Na^+ , Ca^{2+} , Mg^{2+}) via flame photometry and atomic absorption spectrophotometry, Micronutrients (Fe, Mn, Zn, Cu, B) (30). All laboratory analyses adhered to standard protocols at the Soil and Water Laboratory, Institute of Agricultural Research and Training (IAR and), Ibadan (2023). Data observations were recorded at 2, 4, 6, and 8 weeks after transplanting (WAT) on five randomly selected tomato plants per plot. Agronomic parameters such as vegetative growth measurement which includes Stand Count: number of surviving plants per plot at 2 and 8 WAT, Plant Height (cm): Measured from the base to the apex using a meter rule, Number of Leaves: Total number of functional, fully expanded leaves were counted per plant visually, Number of Flowers: Total count of fully opened flowers per plant. The reproductive and Yield Parameters measured were number of fruits per plot: total fruits harvested at physiological maturity, fresh fruit weight (g): was recorded using a precision digital balance scale immediately after harvest, Dry Fruit Weight (g): Fruits were sun-dried at approximately 70 °C for three days before weighing, Total Fresh Yield per Plot (kg): added record of fresh fruit weights per plot. The collected data were subjected to analysis of variance (ANOVA) using SAS software (Version 9.4; SAS Institute Inc., Cary, NC, USA). The treatment means were separated using Fisher's Protected Least Significant Difference (LSD) test at a 5% level of significance ($p \leq 0.05$).

3 Results and Discussion

3.1 Physical and Chemical Properties of the Soil Tested Before Planting in 2023 and 2024

The observations of the pre-planting soil analysis for the experimental field in 2023 and 2024 are presented in Table 1 as recorded in 2023, the soil was Classified as Ibadan series with an organic carbon (O.C) content of 0.74%, with correspondent organic matter (O.M) content of 1.25% while total nitrogen (TN) was 0.60%, potassium (K) concentration was $0.15 \text{ Cmol kg}^{-1}$, and calcium (Ca) was relatively high at $3.10 \text{ Cmol kg}^{-1}$. The available phosphorus (P) concentration was 209 mg kg^{-1} , and the iron (Fe) content was measured at 8.7 mg kg^{-1} . The soil texture was dominated by sand (68%) with minimal clay (3%)

and moderate silt content. The documented observation in 2024 later season of the soil showed a slight decline in organic carbon (0.50%) and organic matter (0.86%) compared to 2023 season, which indicated a potential depletion of soil organic material over the one-year interval. However, total nitrogen increased to 0.71%, showed an enhanced nitrogen availability due to previous organic matter mineralization or fertilizer residues. Exchangeable potassium (K) and calcium (Ca) levels was slightly declined compared to 2023 while a notable increase was recorded in iron (Fe) content (11 mg kg^{-1}) and available phosphorus (275 mg kg^{-1}) in 2024. Texturally, the soil showed a substantial decrease in sand coarseness (7.12%) and a corresponding increase in clay (8%) and silt (10%), which gave a shift towards a slightly finer soil texture in 2024 compared to the previous year, as observed with the organic matter content was decreased between 2023 and 2024 with record improvements in available nutrients: nitrogen and phosphorus that potentially benefited crop growth. The baseline soil conditions were essential due to the response of tomato plants to the different dried sunflower compost and sunflower fresh extract treatments applied during the experiments.

3.2 The Chemical Composition of Poultry Manure, Dried Sunflower Leave Compost and the Sunflower Leaf Extracts

The chemical analysis of animal (poultry manure) as control experiment, dried sunflower leave compost, and sunflower leaf compost extracts (both undiluted and diluted) are presented in Table 2. The dried sunflower leave compost exhibited the highest organic carbon (O.C) content (27.00%) and organic matter (O.M) (33.70%), which indicated their strong potential as a carbon source for soil amendment. From the observation recorded poultry manure showed a considerable organic matter content (33.10%) but a lower organic carbon concentration (11.40%), this shows that it was partially decomposed. The total nitrogen (T.N) was highest in the undiluted sunflower leaf extract (1.76%), followed by the diluted extract (1.38%), and the dried dry sunflower leaves (0.90%), while the poultry manure had the lowest nitrogen content

Table 1 Physical and chemical properties of soil (2023–2024)

Year	Organic carbon (%)	Total nitrogen (%)	K (cmol kg^{-1})	Na (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	P (mg kg^{-1})	Sand (%)	Clay (%)	Silt (%)
2023	0.74	0.6	0.15	3.1	1.13	2.74	177	2.32	8.7	209	68	3	7
2024	0.5	0.71	0.19	2.25	1.17	0.57	217	2.74	11	275	42	8	10

(0.14%). In comparison to the sunflower leaf extracts, particularly their concentrated form were a source of readily available nitrogen for crop uptake. The potassium (K) levels were also extremely high in the sunflower leaf extracts, with the undiluted and diluted concentrations recording 110.09% and 105.21% respectively. The high potassium concentration recorded marked strong fertilizer potential for potassium-demanding crops like tomato. In contrast, the dried sunflower leaves (0.27%) and poultry manure (0.33%) contained lower potassium concentrations. With regard to other macronutrients, calcium (Ca) and magnesium (Mg) were also markedly higher in the sunflower leaf extracts compared to poultry manure and dried sunflower leaves, with undiluted extracts showing 26.52% Ca and 39.38% Mg. This result showed the potential of sunflower extracts not only as nitrogen boosters but also as suppliers of key secondary nutrients. For the micronutrients, particularly manganese (Mn), copper (Cu), zinc (Zn), iron (Fe), and phosphorus (P), the sunflower extracts again demonstrated superior levels compared to poultry manure and sunflower dried leaves. The undiluted extract showed particularly high iron (13.62%) and phosphorus (12.18%) contents essential for tomato fruiting and its quality improvement. The sunflower leaf extracts, especially when undiluted, offered a nutrient-rich organic fertilizer alternative capable to enhance soil fertility and the promotion of vigorous crop growth. The dried sunflower leaves and poultry manure also had substantial organic matter inputs beneficial for the improvement of soil structure and nutrient-holding capacity.

Monthly Agro-Meteorological Observations for 2023: The climatic conditions observed during 2023 at NIHORT were generally suitable for tomato cultivation. The agro-meteorological data collected at NIHORT, Ibadan in 2023 (Table 3) reflected the typical bimodal rainfall pattern and climate characteristics of the rainforest-transition zone of Southwestern Nigeria. The rainfall recorded was highly variable across the year, with peak values recorded

in May (226.2 mm) and September (229.0 mm), which coincided with the early and late planting seasons, respectively. These periods of rainfall were good for nursery field establishment and crop development phases. Conversely, the dry months such as February (0.0 mm) and December (0.0 mm) represented a typical dry-season conditions where supplemental irrigation would be necessary for crop survival and ripening. The temperature trends revealed a consistent high maximum temperatures, ranging from 28.9 °C in August to 36.4 °C in February as the mean temperatures fluctuated between 25.7 °C and 30.3 °C which supported vigorous crop growth but with posed risks of heat stress, particularly in the dry months. February showed the highest mean temperature (30.3 °C), that aligned with the period of highest evapotranspiration demand. The relative humidity remained relatively high throughout the year with peak humidity in May (73.6%) with the onset of the primary growing season with the higher relative humidity levels which gave a leverage to the reduction of evapotranspiration rates and favour the incidence of fungal diseases with the sunshine hours ranging from 1.95 hours in August (cloudy, peak rainy season) to 6.3 hours in April that showed a favourable light conditions for photosynthesis during the planting seasons. Thus, the soil temperature measurements at different depths indicated stable subsurface thermal conditions, with deeper soil layers (30 cm and 50 cm) with a slightly higher temperatures compared to surface layers (10 cm, 20 cm). The maximum soil temperature recorded at 10 cm depth occurred in March (30.5 °C) and February (29.8 °C) that favoured a rapid seedling emergence and root development during early crop establishment. The evaporation rates observed were highest during the dry periods (January to March) and aligned the periods of low rainfall and high temperatures.

Table 2 Chemical composition of organic amendments: poultry manure, dried dry sunflower leaves and sunflower leaf extracts

Sample	Organic carbon (%)	Organic matter (%)	Total nitrogen (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Mn (%)	Cu (%)	Zn (%)	Fe (%)	P (%)
Poultry manure	11.4	33.1	0.14	0.33	2.71	13.75	0.57	0.35	0.02	0.09	0.35	0.81
Dried sunflower leaves	27.0	33.7	0.9	87.27	13.03	14.0	19.36	0.14	0.15	0.1	0.25	8.25
Sunflower leaf extract (undiluted)	7.74	9.52	1.76	110.09	16.54	26.52	39.38	2.38	5.9	5.12	13.62	12.18
Sunflower leaf extract (diluted)	5.92	8.76	1.38	105.21	10.62	23.21	29.69	3.12	7.49	4.72	9.91	16.73

K – potassium, Na – sodium, Ca – calcium, Mg – magnesium, Mn – manganese, Cu – copper, Zn – zinc, Fe – iron, P – phosphorus

Table 3 Monthly agro-meteorological data for 2023 (NIHORT, Ibadan)

Month	Rainfall (mm)	Relative humidity (%)	Max temp (°C)	Min temp (°C)	Mean temp (°C)	Sunshine (h)	Evaporation (mm)	Soil temp (°C, 10 cm)	Soil temp (°C, 20 cm)	Soil temp (°C, 30 cm)	Soil temp (°C, 50 cm)
Jan	32.0	56.2	35.4	20.7	28.1	4.0	4.0	27.1	28.1	28.2	29.5
Feb	0.0	56.7	36.4	24.2	30.3	3.3	3.6	29.8	30.1	30.5	33.8
Mar	150.3	59.1	34.8	24.4	29.5	2.9	3.9	30.5	30.7	31.1	31.4
Apr	68.2	63.1	34.2	24.4	29.2	6.3	4.5	29.8	30.0	30.7	31.0
May	226.2	73.6	33.5	24.3	29.0	5.1	2.4	28.8	29.1	29.5	31.0
Jun	150.5	72.0	30.6	22.7	26.7	4.0	2.0	28.0	28.2	28.5	28.7
Jul	65.2	72.7	29.7	23.4	26.3	2.8	1.5	25.9	27.1	27.6	27.7
Aug	63.6	72.8	28.9	22.7	25.7	2.0	2.2	26.1	26.5	26.7	27.0
Sep	229.0	68.9	30.5	23.6	26.9	2.7	1.2	26.6	26.8	26.8	30.4
Oct	155.4	65.3	32.3	22.6	28.0	4.9	2.4	27.4	27.6	27.9	28.2
Nov	5.9	65.3	32.7	22.5	27.6	5.5	4.2	28.5	28.7	29.1	29.3
Dec	0.0	56.6	35.3	22.5	25.8	5.5	6.5	29.3	29.7	30.3	30.7

Source: Department of water and agrometeorology, NIHORT, Idi-Ishin, Ibadan (2023)

3.3 Monthly Agro-Meteorological Observations for 2024

The agro-meteorological conditions at NIHORT, Ibadan during 2024 (Table 4) highlighted distinct seasonal patterns, crucial for tomato crop performance under variable weather conditions. The rainfall distribution was consistent with the region's bimodal rainfall pattern, with peaks recorded in July (156.0 mm) and May (146.0 mm). These rainfall peaks are vital for soil moisture replenishment and crop development during the early and late cropping seasons. However, low rainfall months, occurrence in February (0.0 mm) and December (0.0 mm) reinforced the need for irrigation to support year-round cultivation. Temperature trends indicated consistently high maximum temperatures, reaching 36.4 °C in February and 35.8 °C in March. These elevated temperatures could potentially induce heat stress during the dry season if not properly managed. The lowest mean monthly temperatures were observed between July (25.7 °C) and August (25.5 °C), coinciding with periods of maximum rainfall and cloud cover. Relative humidity levels were considerably high throughout the year, peaking at 85.5% in July, which enhances vegetative growth but may increase the risk of fungal infections, necessitating proactive crop protection strategies. The Sunshine hours were highest in March (6.1 hours), supporting vigorous photosynthesis at the onset of the first cropping season. Sunshine declined sharply in the peak rainy season (July–September), with minimum values recorded in September (1.9 hours), affecting light availability for crops. Soil temperature data showed that surface and subsurface temperatures were fairly stable

across the year. Soil temperatures at 10 cm to 50 cm depths remained within optimal ranges for tomato root development, particularly between 25.9 °C and 33.2 °C. The warm soil temperatures during March and April were particularly beneficial for rapid seedling establishment and early root proliferation. Evaporation rates were higher during the dry season (January–March), with a maximum of 5.5 mm day⁻¹ recorded in February, reflecting high atmospheric water demand. In conclusion the agro-meteorological conditions in 2024 were favourable for tomato cultivation, provided adequate water management was ensured during dry spells and disease management strategies were implemented during periods of high humidity.

3.4 Effects of dry Sunflower Leaves and Sunflower Leaf Extract on Tomato Plant Height in 2023

The effects of different rates of dry sunflower leaves and sunflower leaf extract on tomato plant height at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2023 early and late cropping seasons are presented in Table 5. At 2 and 4 WAT, neither fresh sunflower leaf application nor sunflower leaf extract significantly affected plant height during both early and late seasons, suggesting that early vegetative growth was relatively uniform across treatments. However, at 6 and 8 WAT, fresh sunflower leaf application rates significantly ($p \leq 0.05$) influenced tomato plant height. Plants treated with 3 t ha⁻¹ of dry sunflower leaves achieved the tallest heights at both stages in both seasons, reaching 51.1 cm and 53.7 cm at 6 WAT during the early and late seasons, respectively. This indicates that higher organic nutrient inputs positively

Table 4 Monthly agro-meteorological data for 2024 (NIHORT, Ibadan)

Month	Rainfall (mm)	Relative humidity (%)	Max temp (°C)	Min temp (°C)	Mean temp (°C)	Sunshine (h)	Evaporation (mm)	Soil temp (°C, 10 cm)	Soil temp (°C, 20 cm)	Soil temp (°C, 30 cm)	Soil temp (°C, 50 cm)
Jan	15.9	69.5	35.3	22.4	28.9	4.0	4.5	29.6	29.5	31.0	30.9
Feb	0.0	70.7	36.4	23.9	30.2	4.2	5.5	29.8	30.0	31.6	31.6
Mar	34.3	68.1	35.8	24.2	30.0	6.1	5.4	31.6	32.1	32.8	33.2
Apr	112.8	73.8	34.4	23.7	29.1	5.6	4.4	29.8	29.3	30.5	30.8
May	146.0	80.8	32.4	23.1	27.8	5.2	2.4	28.2	28.5	28.8	29.3
Jun	111.0	80.8	30.4	23.0	26.7	4.5	1.4	28.0	28.2	28.5	28.7
Jul	156.0	85.5	29.1	22.2	25.7	2.1	1.5	25.9	27.1	27.6	27.7
Aug	90.0	81.0	28.3	22.7	25.5	3.4	1.6	26.1	26.5	26.7	27.0
Sep	52.0	77.3	29.0	21.4	25.2	1.9	1.6	26.6	26.8	26.8	30.4
Oct	90.2	82.2	32.0	23.1	27.6	4.4	2.5	27.4	27.6	27.9	28.2
Nov	45.6	75.5	34.1	23.0	28.6	5.7	3.4	28.5	28.7	29.1	29.3
Dec	0.0	77.3	33.7	21.1	27.4	4.2	2.0	29.3	29.7	30.3	30.7

Source: Department of land and water management and agrometeorology, NIHORT, Idi-Ishin, Ibadan (2024)

influenced late vegetative growth and plant vigour. In contrast, sunflower leaf extract application (0, 1000, and 2,000 l ha⁻¹) showed no significant effect on plant height at any sampling stage in either season, which suggested that the foliar application of sunflower extract alone may be insufficient to markedly influence stem elongation under the conditions of this study, as there were no significant interactions between the rates of dry sunflower leaves and fresh sunflower leaf extract across all sampling periods, thus indicating the independent

effects of the two treatments on plant height. Hence, the soil application of dry sunflower leaves at higher rates (especially 3 t ha⁻¹) enhances tomato vegetative growth more effectively than fresh sunflower leaf extract spraying alone during the 2023 growing seasons.

3.5 Effects of dry Sunflower Leaves and Sunflower Leaf Extract on Tomato Plant Height in 2024

The results of fresh sunflower leaf and sunflower leaf extract applications on tomato plant height at 2, 4, 6,

Table 5 Effects of dry sunflower leaves and sunflower leaf extract application rates on tomato plant height (cm) at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2023 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2023	Late 2023	Early 2023	Late 2023
Dry sunflower leaves eate (t ha⁻¹)				
0	22.6	28.8	36.5	40.1
1	25.0	31.7	41.1	43.1
2	26.5	33.2	44.8	47.4
3	28.2	34.8	51.1	53.7
LSD _(0.05)	ns	ns	4.94*	3.79*
Sunflower leaf extract rate (l ha⁻¹)				
0	24.9	31.3	41.1	44.1
1,000	25.5	31.9	43.2	46.0
2,000	26.3	33.1	45.7	48.2
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	ns

SM – dry sunflower leaves application rate; S – sunflower leaf extract rate, ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

Table 6 Effects of dry sunflower leaves and sunflower leaf extract application rates on tomato plant height (cm) at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2024	Late 2024	Early 2024	Late 2024
Dry sunflower leaves rate (t ha⁻¹)				
0	33.0	30.5	46.8	28.3
1	37.2	32.8	50.0	30.7
2	39.7	34.1	51.6	32.5
3	42.5	36.2	57.0	34.8
LSD _(0.05)	2.79*	1.67*	3.22*	1.80*
Sunflower leaf extract rate (l ha⁻¹)				
0	37.0	32.3	50.0	30.6
1,000	38.1	33.7	51.4	31.5
2,000	39.3	34.2	52.6	32.6
LSD _(0.05)	ns	ns	1.05*	0.42*
Interaction (M × S)	ns	ns	ns	ns

M – dry sunflower leaves application rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons are presented in Table 6. The application of dry sunflower leaves significantly ($p \leq 0.05$) increased plant height at all stages (2, 4, 6, and 8 WAT) during both the early and late seasons. Tomato plants treated with 3 t ha⁻¹ of dry sunflower leaves consistently recorded the greatest plant heights across all observation periods, reaching 42.5 cm and 36.2 cm at 2 WAT, and 57.0 cm and 34.8 cm at 6 WAT during the early and late seasons, respectively. These findings suggest that increasing the rate of dry sunflower leaves improves early vegetative growth and plant establishment. In terms of sunflower leaf extract application, significant effects ($p \leq 0.05$) were observed only at 6 and 8 WAT. Application of 2,000 dm³ ha⁻¹ sunflower leaf extract yielded taller plants than the lower extract rates, with maximum heights recorded at these growth stages. This indicates that the positive effect of sunflower leaf extract becomes more pronounced later in the plant's growth cycle. There were no significant interactions between sunflower leaf rates and sunflower leaf extract rates across all sampling periods, these also suggests that the effects of soil-applied dry sunflower leaves and foliar-applied fresh extracts on plant height were independent of each other. Hence, higher rates of dry sunflower leaf application (3 t ha⁻¹) notably enhanced tomato plant growth, and the sunflower leaf extract at 2,000 dm³ ha⁻¹ provided additional benefits during mid to late vegetative stages.

3.6 Effects of dry Sunflower Leaves and Sunflower Leaf Extract Rates on Tomato Number of Leaves in 2023

The influence of dry sunflower leaves and sunflower leaf extract rates on the number of leaves per tomato plant at 2, 4, 6, and 8 weeks after transplanting (WAT) (Table 7) during the 2023 early and late cropping seasons was evaluated. The application of dry sunflower leaves significantly ($p \leq 0.05$) increased the number of leaves at 6 and 8 WAT in both early and late seasons. Tomato plants amended with 3 t ha⁻¹ of dry sunflower leaves recorded the highest leaf counts, achieving 24.1 leaves and 22.96 leaves per plant at 6 WAT and 8 WAT, respectively, during the early and late seasons. This progressive increase in foliage production indicated improved vegetative growth associated with higher organic matter input from the dry sunflower leaves. It is in contrast to the application of fresh sunflower leaf extract which did not significantly affect the number of leaves at any stage (2, 4, 6, or 8 WAT). Nevertheless, a numerical trend was observed where the 2,000 dm³ ha⁻¹ rate of fresh sunflower leaf extract consistently resulted in slightly higher leaf counts compared to lower extract rates, this suggests a potential but statistically non-significant stimulatory effect since there is no significant interaction effects (M × S) observed between dry sunflower leaf rates and fresh sunflower leaf extract application rates across all measured periods. The dry sunflower leaf application is more influential than fresh sunflower compost foliar extract spraying in the promotion of leaf development in tomato, particularly during critical vegetative growth phases.

Table 7 Effects of dry sunflower leaves and fresh sunflower leaf extract rates on tomato number of leaves at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2023 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2023	Late 2023	Early 2023	Late 2023
Dry sunflower leaves rate (t ha⁻¹)				
0	8.0	8.49	15.9	15.18
1	10.9	10.50	18.7	18.32
2	12.3	11.79	20.8	18.06
3	15.1	14.94	24.1	22.96
LSD _(0.05)	ns	ns	2.01*	4.47*
Sunflower leaf extract rate (l ha⁻¹)				
0	10.8	10.64	18.8	17.31
1000	11.6	11.34	19.9	18.22
2000	12.5	12.31	20.9	20.36
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

3.7 Effects of dry Sunflower Leaves and Sunflower Leaf Extract Rates on Tomato Number of Leaves in 2024

The effects of varying rates of dry sunflower leaves and fresh sunflower leaf extract on the number of leaves (Table 8) per tomato plant at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons were evaluated. A significant ($p \leq 0.05$) increase in the number of leaves was observed with the application of dry sunflower leaves at all growth stages evaluated (2, 4, 6, and 8 WAT). The highest leaf numbers were recorded with the application of 3 t ha⁻¹ of the dry sunflower leaves, with mean values of 14.6 and 11.8 leaves per plant at 2 WAT, which progressively increased to 23.0 and 14.8 leaves at 8 WAT in the early and late seasons, respectively. This consistent enhancement indicates that organic amendments from dry sunflower biomass contributed significantly to improved vegetative vigour and canopy development. Conversely, the application of sunflower leaf extract at varying rates (0, 1000, and 2,000 l ha⁻¹) showed no statistically significant effects on the number of leaves at any stage. Nevertheless, similar to trends in 2023, the presented numerical increment with the 2,000 dm³ ha⁻¹ treatment suggested a potential role of fresh sunflower compost foliar extracts in promoting slight vegetative growth, albeit insufficient to produce significant effects. No significant interaction (M × S) between dry sunflower leaves and fresh sunflower leaf extract treatments was detected throughout the assessment period. Hence the soil amended with dry sunflower leaves is more effective than fresh sunflower foliar spraying of extracts in the enhancement of tomato vegetative growth, which

was likely due to better soil nutrient enrichment and microbial stimulation associated with organic residue incorporation.

3.8 Effects of dry Sunflower leaves and Sunflower Leaf Extract on Fresh Fruit Weight of Tomato in the 2023 Cropping Seasons

The results presented in Table 9 show that the application of dry sunflower leaves significantly ($p \leq 0.05$) influenced the fresh fruit weight of tomato plants at all stages measured (2, 4, 6, and 8 WAT) during both early and late 2023 cropping seasons. At 2 WAT, tomato plants treated with 3 t ha⁻¹ dry sunflower leaves exhibited the highest fresh fruit weight (5.64 g in early season and 0.99 g in late season) compared to the control (1.61 g and 0.29 g, respectively). This trend continued through 4 WAT, 6 WAT, and 8 WAT, with the highest recorded fresh fruit weight of 31.05 g and 6.94 g at 8 WAT under the 3 t ha⁻¹ treatment. Conversely, application of sunflower leaf extract (0, 1,000, and 2,000 l ha⁻¹) did not significantly influence fresh fruit weight across all stages, although numerically higher values were observed at the highest extract rate (2,000 l ha⁻¹), particularly at later growth stages. The absence of a significant interaction (M × S) between soil-applied dry sunflower leaves and foliar-applied leaf extract indicates that their effects on fresh fruit weight were independent which emphasized that soil amendment with dry sunflower leaves at 3 t ha⁻¹ substantially enhanced tomato fruit biomass production, likely through improved soil fertility and nutrient availability, while foliar applications of sunflower extract exert a relatively minor effect.

Table 8 Effects of dry sunflower leaves and fresh sunflower leaf extract rates on number of leaves of tomato at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2024	Late 2024	Early 2024	Late 2024
Dry sunflower leaves rate (t ha⁻¹)				
0	9.9	7.6	14.1	10.6
1	11.6	8.8	17.6	11.7
2	12.4	10.1	20.0	13.2
3	14.6	11.8	23.0	14.8
LSD _(0.05)	1.18*	1.59*	3.22*	1.53*
Sunflower leaf extract rate (l ha⁻¹)				
0	11.3	9.2	17.3	12.1
1,000	12.0	9.6	18.9	12.6
2,000	13.1	10.0	19.9	13.1
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

Table 9 Effects of dry sunflower leaves and sunflower leaf extract rates on plant fresh weight (g) of tomato fruits at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2023 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2024	Late 2024	Early 2024	Late 2024
Dry sunflower leaves rate (t ha⁻¹)				
0	9.9	7.6	14.1	10.6
1	11.6	8.8	17.6	11.7
2	12.4	10.1	20.0	13.2
3	14.6	11.8	23.0	14.8
LSD _(0.05)	1.18*	1.59*	3.22*	1.53*
Sunflower leaf extract rate (l ha⁻¹)				
0	11.3	9.2	17.3	12.1
1,000	12.0	9.6	18.9	12.6
2,000	13.1	10.0	19.9	13.1
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

3.9 Effects of dry Sunflower leaves and Sunflower Leaf Extract on Fresh Fruit Weight of Tomato in the 2024 Cropping Seasons

The application of dry Sunflower leaves (Table 10) significantly ($p \leq 0.05$) influenced the fresh fruit weight of tomato plants at 2, 4, and 8 WAT during both the early and late cropping seasons of 2024 at NIHORT, Ibadan.

At 2 WAT, the highest fresh fruit weight was observed with the application of 3 t ha⁻¹ of dry sunflower leaves

(2.0 g early season; 5.2 g late season), compared to the control plots (0.7 g and 2.2 g, respectively). A similar trend persisted at 4 WAT and 8 WAT, with the 3 t ha⁻¹ treatment recording the greatest fresh fruit biomass (7.4 g and 5.4 g, respectively). However, at 6 WAT, differences among treatments were not statistically significant ($p > 0.05$), indicating a temporary equilibration of growth responses across treatments during mid-season. The foliar applications of sunflower leaf extract

(0; 1,000, and 2,000 l ha⁻¹) did not result in statistically significant differences in fresh fruit weight at any time point. Although numerically higher fruit weights were observed under 2000 l ha⁻¹, the improvements were not significant. Moreover, there was no significant interaction ($M \times S$) between soil-applied dry sunflower leaves and foliar-applied fresh sunflower leaf compost extract, which suggested that their effects were independent and additive rather than synergistic. Hence, the application of 3 t ha⁻¹ of dry sunflower leaves consistently enhanced tomato fruit biomass across both early and late 2024 cropping seasons, reinforcing the importance of organic soil amendments over foliar supplementation alone for optimal tomato production under field conditions.

3.10 Effects of dry Sunflower leaves and Sunflower Leaf Extract Application Rates on Dry Plant Weight of Tomato in 2023 Cropping Seasons

The application of dry sunflower leaves and fresh sunflower leaf compost extract (Table 11) generally increased the dry plant weight of tomato at 2, 4, 6, and 8 WAT during both early and late 2023 seasons at NIHORT, Ibadan. There were no statistically significant differences ($p > 0.05$) among the treatments for dry plant weight at 2, 4, and 6 WAT, as the trend was observed. Plots amended with 3 t ha⁻¹ of dry sunflower leaves consistently recorded higher dry biomass than control plots. At 8 WAT, tomato plants treated with 3 t ha⁻¹ exhibited dry weights of 1.74 g (early season) and 0.65 g (late season), compared to the control treatments with 0.82 g and 0.31 g, respectively. Similarly, foliar application of sunflower leaf

extract, although not statistically significant, showed a slight numerical advantage, particularly at 6 and 8 WAT. Interestingly, a significant interaction ($M \times S$) was observed at 8 WAT ($p \leq 0.05$), suggesting that the combined application of dry sunflower leaves and fresh sunflower compost foliar extract at specific rates enhanced the dry matter accumulation of tomato plants more than either treatment alone at the late vegetative stage. While statistical significance was limited at early stages, the application of 3 t ha⁻¹ of dry sunflower leaves, especially in combination with 2,000 dm³ ha⁻¹ of fresh sunflower compost foliar extract, showed a promising trend for the enhancement of dry biomass accumulation at the crucial stages of tomato growth.

3.11 Effects of dry Sunflower leaves and Sunflower Leaf Extract Application Rates on Dry Plant Weight of Tomato in 2024 Cropping Seasons

The effects of dry sunflower leaves and sunflower leaf extract rates on dry plant weight of tomato (Table 12) at 2, 4, 6, and 8 WAT during the 2024 early and late cropping seasons at NIHORT, Ibadan were evaluated. There was an increased trend in dry matter accumulation with higher application rates of dry sunflower leaves, although the differences were not statistically significant ($p > 0.05$) across all sampling periods. At 8 WAT, the highest dry weights were observed in plots treated with 3 t ha⁻¹ of dry sunflower leaves, reaching 3.3 g (early season) and 1.7 g (late season), compared to the control plots with 0.8 g and 0.8 g, respectively. Similar observations, were seen in the foliar applications of sunflower leaf

Table 10 Effects of dry sunflower leaves and sunflower leaf extract rates on plant fresh weight (g) of tomato fruits at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2024	Late 2024	Early 2024	Late 2024
Dry sunflower leaves rate (t ha⁻¹)				
0	0.7	2.2	2.2	2.0
1	0.9	3.2	3.8	2.4
2	1.4	3.9	5.5	3.7
3	2.0	5.2	7.4	5.4
LSD _(0.05)	0.49*	0.99*	ns	1.2*
Sunflower leaf extract rate (l ha⁻¹)				
0	1.1	3.3	4.0	3.0
1,000	1.2	3.7	4.7	3.3
2,000	1.5	3.9	5.5	4.2
LSD _(0.05)	ns	ns	ns	ns
Interaction ($M \times S$)	ns	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ using Fisher's protected least significant difference (LSD) test

Table 11 Effects of dry sunflower leaves rates and spraying of sunflower leaf extract on dry plant weight (g) of tomato at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2023 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2023	Late 2023	Early 2023	Late 2023
Dry sunflower leaves rate (t ha⁻¹)				
0	0.17	0.16	0.82	0.31
1	0.25	0.22	1.12	0.41
2	0.32	0.26	1.37	0.52
3	0.40	0.34	1.74	0.65
LSD _(0.05)	ns	ns	ns	ns
Sunflower leaf extract rate (l ha⁻¹)				
0	0.26	0.22	1.14	0.43
1,000	0.28	0.25	1.25	0.47
2,000	0.32	0.27	1.39	0.52
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	0.1*

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

extract with incremental improvements in dry plant weight with increased extract concentration, though these differences were also not statistically significant. However, the maximum dry weights were obtained with 2,000 dm³ ha⁻¹ of sunflower leaf extract, with minimal production of 2.1 g (early season) and 1.4 g (late season) at 6 and 8 WAT. No significant interaction (M × S) effects were detected throughout the measurement periods, with the evidence that dry sunflower leaf application and

fresh sunflower compost foliar extract treatments acted independently to influence the tomato dry biomass. The observed improvements, albeit statistically non-significant, suggested that organic amendments using sunflower-based materials can potentially enhance tomato biomass accumulation over time under field conditions, especially during periods of sub-optimal environmental conditions.

Table 12 Effects of dry sunflower leaves rates and spraying of sunflower leaf extract on dry plant weight (g) of tomato at 2, 4, 6, and 8 weeks after transplanting (WAT) during the 2024 early and late cropping seasons at NIHORT, Ibadan

Treatments	2 WAT	4 WAT	6 WAT	8 WAT
	Early 2024	Late 2024	Early 2024	Late 2024
Dry sunflower leaves rate (t ha⁻¹)				
0	0.4	0.5	0.8	0.8
1	0.5	0.6	1.4	1.1
2	0.6	0.8	2.1	1.4
3	0.8	1.2	3.3	1.7
LSD _(0.05)	ns	ns	ns	ns
Sunflower leaf extract rate (l ha⁻¹)				
0	0.5	0.7	1.7	1.1
1,000	0.6	0.7	1.9	1.3
2,000	0.6	1.0	2.1	1.4
LSD _(0.05)	ns	ns	ns	ns
Interaction (M × S)	ns	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

Application of dry Sunflower leaves and sunflower leaf extract significantly influenced tomato yield components across both early and late 2023 cropping seasons at NIHORT, Ibadan.

3.12 Effect of dry sunflower leaves rate

The rate of dry sunflower leaves increased from 0 to 3 t ha⁻¹ and led to a consistent and significant enhancement in fresh and dry fruit weights across seasons ($p \leq 0.05$). Fresh fruit weight increased from 724.5 kg ha⁻¹ at 0 t ha⁻¹ to 1,045.5 kg ha⁻¹ at 3 t ha⁻¹ during the early season, and from 280.0 to 818.0 kg ha⁻¹ during the late season, demonstrating a clear dose-dependent response. Similarly, dry fruit weight increased proportionally with higher dry leaf application. However, while the number of fruits per plant also increased with leaf application (from 94.5 to 268 fruits per plant), the effect was not statistically significant, and this trend indicated that the biomass gain per fruit rather than fruit number may have contributed more substantially to yield improvements.

3.13 Effect of Sunflower Leaf Extract Rate

The foliar application of sunflower leaf extract also exerted a significant positive effect on fresh fruit weight, dry fruit weight, and number of fruits per plant ($p \leq 0.05$). Notably, the fresh fruit weight increased from 831.5 to 907.0 kg ha⁻¹, and dry fruit weight from 451.0 to 602.5 kg ha⁻¹, with increased extract concentration (0 to 2,000 dm³ ha⁻¹). The number of fruits per plant increased significantly, this shows that the sunflower leaf extract not only enhanced fruit biomass but also

promoted fruit set. Hence the interaction between dry sunflower leaves and sunflower leaf extract rates was not statistically significant ($p > 0.05$) for any measured parameters. This suggests that the benefits derived from the two inputs were primarily additive and independent, rather than synergistic. Thus, the findings emphasized the agronomic potential of sunflower-based organic inputs in the enhancement of tomato production under tropical field conditions. The clear positive response of fruit yield components to both soil and foliar applications evidently suggested that dry sunflower residues and extracts could serve as sustainable, low-cost alternatives or complements to conventional fertilizers. The lack of significant interaction implied the flexibility for tomato growers to apply either treatment independently based on resource availability. Thus, future work should focus more on optimizing application timing and elucidating the underlying physiological mechanisms driving these yield enhancements.

3.14 Effect of dry Sunflower leaves Rate

The application of dry sunflower leaves significantly increased fresh fruit weight, dry fruit weight, and number of fruits per plot ($p \leq 0.05$). Fresh fruit weight rose markedly from 64.0 kg ha⁻¹ (0 t ha⁻¹) to 333.0 kg ha⁻¹ (3 t ha⁻¹) during the early season, and from 51.0 to 280.0 kg ha⁻¹ in the late season. Similarly, dry fruit weight followed an increased trend, with the indication that improved partitioning of biomass into harvestable yield. The number of fruits per plot displayed a dramatic increase, particularly at the highest application rate (316 fruits at 3 t ha⁻¹), relaying

Table 13 Effects of dry sunflower leaves rates and spraying of sunflower leaf extract on fresh fruit weight (kg ha⁻¹), dry fruit weight (kg ha⁻¹), and number of fruits per tomato plant at harvest during the 2023 early and late 2024 cropping seasons at NIHORT, Ibadan

Treatments	Fresh fruit weight (kg ha ⁻¹)	Dry fruit weight (kg ha ⁻¹)	Number of fruits per plant
	Early 2023	Late 2023	Early 2023
Dry sunflower leaves rate (t ha⁻¹)			
0	724.5	280.0	94.5
1	814.5	430.0	126.5
2	901.0	584.0	194.0
3	1045.5	818.0	268.0
LSD (0.05)	157.5*	194.5*	ns
Sunflower leaf extract rate (l ha⁻¹)			
0	831.5	451.0	146.0
1,000	876.0	531.0	165.5
2,000	907.0	602.5	200.5
LSD _(0.05)	31.2*	26.2*	28.8*
Interaction (M × S)	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

the potential of dry sunflower biomass to stimulate both reproductive development and fruit retention. The foliar application of fresh sunflower leaf compost extract also exerted a significant and positive effect on all measured parameters ($p \leq 0.05$). Fresh fruit weight increased progressively from 832.0 to 907.0 kg ha⁻¹ across extract rates, with corresponding gains in dry fruit weight and fruit number. The positive linear response suggested that the fresh sunflower leaf compost extract was likely due to its bioactive compounds, enhanced by both vegetative vigour and fruiting efficiency. Hence the interaction between dry sunflower leaves and sunflower leaf extract rates was not significant for any of the traits measured ($p > 0.05$), indicating that each input independently contributed to yield improvements without synergistic or antagonistic effects.

3.15 Discussion

This study evaluated the independent and combined effects of dry sunflower leaves and sunflower leaf compost extract on tomato yield attributes during the early 2023 and late 2024 cropping seasons at NIHORT, Ibadan.

3.15.1 Soil Fertility and Seasonal Variation

The comparative analysis of soil properties across both seasons revealed significant seasonal shifts in fertility parameters, shaped by both organic amendments and prevailing climatic factors. The 2023 results of baseline fertility – moderate organic carbon (0.74%) and organic

matter (1.25%), high calcium (3.10 Cmol kg⁻¹), and phosphorus (209 mg kg⁻¹). These aligned with the Ibadan soil series, which indicated moderate productivity potential for tomato cultivation (30–32, 54). However, by 2024, there were reductions recorded in organic carbon (0.50%) and organic matter (0.86%) which mirrored global patterns of declining soil organic matter in intensively managed tropical soils (Govindasamy et al., 2023, Ali et al., 2020), despite an increase in total nitrogen (0.71%) attributable to residual sunflower treatments that enhanced nitrogen cycling and microbial activity (Durmuş & Kızılkaya, 2022; Abbasi & Khizar, 2012; Abbasi & Khaliq, 2016; Ning et al., 2022). The 2024 planting season recorded increased in available phosphorus (275 mg kg⁻¹) and iron (11 mg kg⁻¹) which may be linked to organic acid production and nutrient chelation from sunflower-based inputs (Sagnon et al., 2024, Bai et al., 2024, Abdelaziz et al., 2007). These nutrients are crucial for tomato development: phosphorus supports root and reproductive development, while iron enhances photosynthesis and enzyme activity (Ali et al., 2014, Kooshki et al., 2024, Srivastava et al., 2024). The texture changes (sand reduced from 68% to 42%, with increases in clay and silt) suggested an improved soil aggregation, which is possibly due to the organic matter-induced microaggregate formation (Ali et al., 2020, Skendžić et al., 2021). These structural improvements foster better water-holding capacity, nutrient retention, and aeration condition conducive for tomato root development and yield (Hossain et al., 2024).

Table 14 Effects of dry sunflower leaves rates and sunflower leaf extract spraying on fresh fruit weight (kg ha⁻¹), dry fruit weight (kg ha⁻¹), and number of fruits per tomato plant at harvest in the 2024 early and late cropping seasons at NIHORT, Ibadan

Treatments	Fresh fruit weight (kg ha ⁻¹)	Dry fruit weight (kg ha ⁻¹)	Number of fruits per plot
	Early 2024	Late 2024	Early 2024
Dry sunflower leaves rate (t ha⁻¹)			
0	64.0	51.0	28.0
1	111.0	57.0	57.0
2	175.0	69.0	92.0
3	333.0	280.0	316.0
LSD _(0.05)	157.0*	42.0*	254.0*
Sunflower leaf extract rate (l ha⁻¹)			
0	832.0	451.0	146.0
1,000	876.0	531.0	166.0
2,000	907.0	603.0	201.0
LSD(0.05)	31.0*	26.0*	29.0*
Interaction (M × S)	ns	ns	ns

M – dry sunflower leaves rate; S – sunflower leaf extract rate; ns – not significant at $p \leq 0.05$; * – significant at $p \leq 0.05$ based on Fisher's protected least significant difference (LSD) test

3.15.2 Nutrient Profile of Organic Inputs

The composition of the organic amendments showed their varied roles. The dry sunflower leaves were high in organic carbon (27.00%) and organic matter (33.70%), thus making it an ideal compost for building soil organic reserves. However, their moderate nitrogen (0.90%) and potassium (87.27 mg kg⁻¹) suggested limited short-term nutrient supply (Adnyana et al., 2025, Carillo, 2025). In contrast, sunflower leaf extract, especially undiluted, had elevated nitrogen (1.76%), potassium (110.09 mg kg⁻¹), calcium, magnesium, phosphorus, and iron which supported its use as a quick-acting foliar nutrient supplement (Ning et al., 2022; Zen El-Dein, 2024; Durmuş and Kızılkaya, 2022). These characteristics are consistent with findings on the effectiveness of liquid organic fertilizers and foliar applications for enhancing physiological performance in crops as reported by Ali et al. (2014); Kooshki et al., (2024); Srivastava et al., 2024 and Rupngam et al. (2025). Although poultry manure also contributed to the organic matter input, its low nitrogen content (0.14%) compared to sunflower inputs confirmed the variability among organic sources and the need for material-specific strategies (Adnyana et al., 2025; Ning et al., 2022). Therefore the combination of high-carbon (e.g., dry sunflower leaves) and high-nitrogen (e.g., foliar extract or compost) sources can synchronize nutrient release with tomato growth stages (Govindasamy et al., 2023; Abbasi and Khizar, 2012).

3.15.3 Agroclimatic Influences on Soil – Crop Interactions

NIHORT's bimodal rainfall pattern supported multiple tomato cycles annually. However, the variability in rainfall distribution influenced the tomato plant growth. While 2023 rainfall peaks enhanced vegetative growth, the reduced early-season rainfall in 2024 induced temporary moisture stress. The organic treatments likely buffered against this, hence an improvement in soil water retention (Zhao et al., 2025, Rayne & Aula, 2020, Hossain et al., 2024). The February–March temperatures exceeded 36 °C in both years, posing heat stress risks during flowering (Onyeneke et al., 2023, Duluora et al., 2025). Nonetheless, the daily mean temperatures (25–30 °C) and optimal subsurface soil temperatures supported consistent plant growth (Yang et al., 2022). High relative humidity (≥ 80%) during peak rains in both years elevated blight and disease risk, which necessitated a robust pest and disease management strategies (Ayankojo & Morgan, 2020, Skendžić et al., 2021).

3.15.4 Agronomic Efficacy of Dry Sunflower Leaves

The dry sunflower leaf treatments, particularly at 3 t ha⁻¹, significantly improved tomato growth and yield as seen in plant height, leaf number, and fresh fruit weight recorded. This result was supported by the hypothesis that sunflower biomass enhances soil fertility and crop vigour through earlier studies by Ning et al., 2022, Carillo, 2025 and Mokgolo et al., 2024. As the yields increased by 1,045.5 kg ha⁻¹ in 2023 and 333.0 kg ha⁻¹ in 2024, it showed consistency with earlier studies on sustainable fertility management using plant-based materials as reported by Zen El-Dein, 2024; Durmuş & Kızılkaya, 2022 and Hossain et al., 2024 in their earlier research studies.

3.15.5 Limited Response to Sunflower Leaf Extract

Foliar application of sunflower leaf extract yielded modest improvements, primarily at 2,000 dm³ ha⁻¹, in final fruit yield rather than vegetative traits, which suggested that while sunflower extract contains bioactive compounds, its full efficacy depends on dosage, frequency, and plant growth stage (Kooshki et al., 2024, Srivastava et al., 2024 and Rupngam et al., 2025), as literature indicated such inputs may act through hormonal or metabolic modulation during flowering and fruiting stage of tomato production (Ali et al., 2014, Talwar et al., 2022).

3.15.6 Treatment Independence and Implications

No significant interactions were observed between dry leaves and foliar extract treatments, which implies that their effects are largely independent. This finding hence provides farmers the flexibility of sunflower residues and extracts application depending on the availability of resources (Abdelaziz et al., 2007, Mokgolo et al., 2024), although the combined treatments were not synergistic as recorded in this study.

4 Conclusions

The results of this study demonstrated that organic amendments derived from *Tithonia diversifolia* significantly improved soil fertility parameters and enhanced tomato growth and yield under tropical field conditions. The integration of plant-based residues and extracts increased soil organic carbon, improved nutrient availability and supported better nutrient use efficiency compared with the control treatment. Treatments combining organic inputs with moderate mineral nitrogen application showed superior performance, thus indicating the effectiveness of integrated nutrient management strategies. The findings confirmed that sunflower leaf residues and extracts can partially substitute inorganic

fertilizers while maintaining productivity and improving soil health indicators. This approach contributes to sustainable horticultural production by enhancing soil structure, promoting nutrient cycling, and reducing reliance on synthetic fertilizer inputs. Therefore, the incorporation of locally available plant-derived organic amendments represents a practical and climate-smart strategy for improving tomato production and long-term soil quality in similar agroecological systems. Hence, future research should evaluate optimized timing, dosage, and formulation to potentially enhance better productivity.

References

- Abbasi, M. K., & Khaliq, A. (2016). Nitrogen mineralization of a loam soil supplemented with organic-inorganic amendments under laboratory incubation. *Frontiers in Plant Science*, 7, 1038. <https://doi.org/10.3389/fpls.2016.01038>
- Abbasi, M. K., & Khizar, A. (2012). Microbial biomass carbon and nitrogen transformations in a loam soil amended with organic-inorganic N sources and their effect on growth and N-uptake in maize. *Ecological Engineering*, 39, 123–132. <https://doi.org/10.1016/j.ecoleng.2011.12.027>
- Abdelaziz, M. E., Pokluda, R., & Abdelwahab, M. M. (2007). Influence of compost, microorganisms and NPK fertilizer upon growth, chemical composition and essential oil production of *Rosmarinus officinalis* L. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 35(2), 86–90.
- Aboloso, P. F., Ogunjimi, S. I., & Abulosoro, S. A. (2014). Farmers' perception on the strategies for increasing tomato production in Kabba-Bunu local government area of Kogi State, Nigeria. *Agrosearch*, 14(2), 144–153.
- Adnyana, I. M., Bimantara, P. O., & Roni, N. G. K. (2025). Enhancing soil fertility through Azolla incorporation: Impacts on nitrogen cycling and cation exchange capacity. *Organic Farming*, 11(1), 1–12. <https://doi.org/10.56578/of110101>
- Ajenifujah-Solebo, O., Akin-Idowu, P. E., Aduloju, A. O., Adediji, V. O., Akinyode, T. E., Ibitoye, D. O., & Bello, F. (2025). Tomato crop improvement efforts in Nigeria: Past, current and future perspectives. *IntechOpen*. <https://doi.org/10.5772/intechopen.1009299>
- Ali, A., Sharif, M., Wahid, F., Zhang, Z., Noor, S., Shah, & M. R., et al. (2014). Effect of composted rock phosphate with organic materials on yield and phosphorus uptake of Berseem and maize. *American Journal of Plant Sciences*, 5(1), 975–984.
- Ali, M. Y., Sina, A. A., Khandker, S. S., Neesa, L., Tanvir, E. M., Kabir, A., Khalil, M. I., & Gan, S. H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, 10(1), 45. <https://doi.org/10.3390/foods10010045>
- Amirahmadi, E., Ghorbani, M., Moudry, J., Konvalina, P., & Kopecký, M. (2023). Impacts of environmental factors and nutrients management on tomato grown under controlled and open field conditions. *Agronomy*, 13(3), 916. <https://doi.org/10.3390/agronomy13030916>
- Ayankojo, I. T., & Morgan, K. T. (2020). Increasing air temperatures and its effects on growth and productivity of tomato in South Florida. *Plants*, 9(9), 1245. <https://doi.org/10.3390/plants9091245>
- Bai, K., Wang, W., Zhang, J., Yao, P., Cai, C., Xie, Z., Luo, L., Li, T., & Wang, Z. (2024). Effects of phosphorus-solubilizing bacteria and biochar application on phosphorus availability and tomato growth under phosphorus stress. *BMC Biology*, 22(1), 211. <https://doi.org/10.1186/s12915-024-02011-y>
- Carillo, P. (2025). Can biostimulants enhance plant resilience to heat and water stress in the Mediterranean hotspot? *Plant Stress*, 16, 100802.
- Ddamulira, G., Malaala, A., Otim, A., Florence, N., & Maphosa, M. (2022). Soil amendments improved tomato growth, yield, and soil properties. *American Journal of Plant Sciences*, 13, 960–971.
- Monthly Agro-Meteorological Data. (2023 and 2024). Department of Land and Water Management and Agrometeorology, National Horticultural Research Institute (NIHORT), Idi-Ishin, Ibadan .
- Duluora, J. O., Ozoemene, M. L., Duluora, N. C., & Obi, O. H. (2025). Climate variability and its effect on tomato yield in Nigeria. *International Journal of Multidisciplinary Research and Growth Evaluation*, 6(3).
- Durmuş, M., & Kızılkaya, R. (2022). The effect of tomato waste compost on yield of tomato and some biological properties of soil. *Agronomy*, 12(6), 1253.
- FAO. (2022). *Food and Agriculture 2022*. <https://doi.org/10.4060/cc0639en>
- FAO. (2023). *The state of food and agriculture 2023: Making agri-food systems more resilient to shocks and stresses*.
- FAOSTAT. (2022). *Tomato production statistics in Africa*. Food and Agriculture Organization of the United Nations.
- Gerakari, M., Kyriakoudi, A., Nokas, D., Mourtzinis, I., Chronopoulou, E. G., Tani, E., & Avdikos, I. (2024). Evaluation of the potential of wild relatives of tomato (*Solanum pennellii*) to improve yield and fruit quality under low-input and high-salinity cultivation conditions. *Agronomy*, 14(12), 3042.
- Gordeyeva, Y., Shelia, V., Shestakova, N., Amantayev, B., Kipshakbayeva, G., Shvidchenko, V., Aitkhozhin, S., Kurishbayev, A., & Hoogenboom, G. (2024). Sunflower (*Helianthus annuus*) yield and yield components for various agricultural practices. *Agronomy*, 14(1), 36.
- Govindasamy, P., Muthusamy, S. K., Bagavathiannan, M., Mowrer, J., Jagannadham, P. T. K., Maity, A., Halli, H. M., Vadivel, R., Raj, R., Pooniya, V., Babu, S., Rathore, S. S., & Tiwari, G. (2023). Nitrogen use efficiency – A key to enhance crop productivity under a changing climate. *Frontiers in Plant Science*, 14, 1121073.
- Hossain, M. M., Sultana, F., & Mostafa, M. et al. (2024). Plant disease dynamics in a changing climate. *Discover Agriculture*, 2, 132.
- Jama, B., Palm, C. A., Buresh, R. J., Niang, A., Gachengo, C., Nziguheba, G., & Amadalo, B. (2000). *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: A review. *Agroforestry Systems*, 49(2), 201–221.
- Kaushal, M., Atieno, M., Odjo, S., Baijukya, F., Gebrehawaryat, Y., & Fadda, C. (2025). Nature-positive agriculture – A way forward towards resilient agrifood systems. *Sustainability*, 17(3), 1151.
- Kooshki, M. J., Haghighi, M., & Mozafarian, M. (2024). Enhancing tomato growth, quality, and yield through bio and nano-bio phosphorus application. *Journal of Agriculture and Food Research*, 18, 101483.

- Kumar, M., Chandran, D., Tomar, M., Bhuyan, D. J., Grasso, S., & Sá, A. G. A. et al. (2022). Valorization potential of tomato (*Solanum lycopersicum* L.) seed. *Horticulturae*, 8(3), 265.
- Li, P., Kong, D., Zhang, H., Xu, L., Li, C., Wu, M., Jiao, J., Li, D., Xu, L., Li, H., & Hu, F. (2021). Different regulation of soil structure and resource chemistry under animal- and plant-derived organic fertilizers. *Applied Soil Ecology*, 165, 104020.
- Liu, W., Liu, K., Chen, D., Zhang, Z., Li, B., El-Mogy, M. M., Tian, S., & Chen, T. (2022). *Solanum lycopersicum*, a model plant for developmental and stress biology studies. *Foods*, 11(16), 2402.
- Mokgolo, M. J., Zerizghy, M. G., & Mzezewa, J. (2024). Sunflower growth and grain yield under different tillage systems. *Agronomy*, 14(4), 857.
- Ning, L., Xu, X., Zhang, Y., Zhao, S., Qiu, S., Ding, W., Zou, G., & He, P. (2022). Effects of chicken manure substitution for mineral nitrogen fertilizer. *Frontiers in Plant Science*, 13, 1050179.
- Omokhua, A. G., Abdalla, M. A., & Van Staden, J., et al. (2018). Potential phytomedicinal use and toxicity of invasive *Tithonia* species. *BMC Complementary and Alternative Medicine*, 18, 272.
- Onyeneke, R. U., Agyarko, F. F., Onyeneke, C. J., Osuji, E. E., Ibeneme, P. A., & Esfahani, I. J. (2023). How does climate change affect tomato and okra production? *Plants*, 12(19), 3477.
- Rayne, N. & Aula, L. (2020). Livestock manure and the impacts on soil health: A review. *Soil Systems*, 4(4), 64.
- Rupngam, T., Udomkun, P., Boonupara, T., & Kaewlom, P. (2025). Enhancing soil health and growth in sunflower sprouts. *Agronomy*, 15(5), 1213.
- Sagnon, A., Traore, M., Tibiri, E. B., Zongo, S., Bonkoungou, I. J. O., Nakamura, S., Barro, N., Tiendrebeogo, F., & Sarr, P. S. (2024). Enhancing the use of phosphate rock through compost transformation. *Frontiers in Sustainable Food Systems*, 8, 1445683.
- Sembiring, K., & Banjarnahor, D. (2024). Effect of compost mix of Mexican sunflower (*Tithonia diversifolia*) green manure and poultry bone meal on productivity and nutritional quality of Red Russian kale (*Brassica napus* var. *pabularia*). *Agro Bali: Agricultural Journal*, 7(3), 989–997.
<https://doi.org/10.37637/ab.v7i3.1925>
- Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects*, 12(5), 440.
- Sparta, A., Hamdani, J. S., Yurwariah, Y., & Wulandari, E. (2025). The role of *Tithonia diversifolia* in sustaining crop productivity in acid soils. *Bulgarian Journal of Agricultural Science*, 31(1), 50–60.
- Srivastava, R. K., Purohit, S., Alam, E., & Islam, M. K. (2024). Advancements in soil management. *Journal of Agriculture and Food Research*, 18, 101528.
- Talwar, S., Bamel, K., Prabhavathi, & Mal, A. (2022). Effect of high temperature on reproductive phase of plants: A review. *Nature Environment and Pollution Technology*, 21(4), 1887–1892.
- Yang, L., Liu, H., Cohen, S., & Gao, Z. (2022). Microclimate and plant transpiration of tomato. *Agriculture*, 12(2), 260.
- Zen El-Dein, A. (2024). Response of tomatoes and sunflower intercropping to organic and mineral fertilization. *Journal of Plant Production*, 15(11), 725–730.
- Zhao, C., Gao, Y., Han, Y., & Yang, X. (2025). Enhanced fine soil aggregation and organic matter accumulation. *Frontiers in Environmental Science*, 13, 1515120.

