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Enhanced Organic Fertilizers as a Partial Alternative to Synthetic Fertilizers: A Sustainable Tool for Improving Maize Productivity and Soil Properties

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IT IS KNOWN that synthetic fertilizers cause environmental and health damage. In this research, various fertilization regimes were implemented with maize plant aiming to reducing reliance on synthetic fertilizers. The treatments were **T_1:** Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), **T_2:** Control$_2$ (50% of NPK - RD as synthetic fertilizers), **T_3:** 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), **T_4:** 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), **T_5:** 50% of NPK-RD as synthetic fertilizers + Compost$_3$ (Cotton stalks +microbial activator),**T_6:** 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), **T_7:** 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast). Before conducting the experiment, the five types of compost were analyzed, and the analysis revealed a clear variation in the properties of these composts. All studied compost were added to the soil at a rate of 35 m^3ha^{-1} according to the studied treatments. Compost$_5$ showed a potential advantage in terms of the expected impact on maize plant performance and soil health (total microbial count), as it contained a higher percentage of organic matter and available nutrients as well as low C/N ratio. Regarding plant performance at 60 and 90 days, the superior treatments was **T_7**, which achieved the highest values of growth criteria (such as plant height, fresh and dry weights and leaf area), photosynthetic pigments (*e.g.,* chlorophyll a & b and carotene), straw content of NPK and ear qualitative and quantitative traits (*e.g.,* grain and biological yield, harvest index, weight of ear, ear length and diameter, No. seeds ear^{-1} and weight of 100 grain, grain content of protein and carbohydrates). The **T_6** came in the second order in terms of effectiveness followed by **T_5, T_1, T_4, T_3** and **T_2,** respectively. Concerning, the soil properties such as available NPK,CEC, OM and total microbial count, all types of compost positively affected these properties, as the order sequence from top effectives to less were **T_7> T_6> T_5> T_4> T_3> T_2> T_1.** Finally, it is recommended to use compost$_{5,4,3}$, to substitute partially Synthetic fertilizers by up to 50% as part of integrated plant nutrition management programs, as this approach achieves high productivity and lower costs. Furthermore, this approach represents a fundamental step toward reducing reliance on expensive synthetic fertilizers with negative environmental influences.

Keywords: Wheat straw**,** Maize residues, Cotton stalks, Bean residues .

1.Introduction

Due to the increasing environmental and health challenges associated with the use of synthetic fertilizers, there is an urgent need to find more sustainable, ecofriendly alternative agricultural approaches. The frequent use of synthetic fertilizers not only diminish soil health and increase contaminates that leach out to groundwater, but also negatively impacts human and animal health, possibly due to the accumulation of nitrates or the existence of heavy metals in the food chain (**Tripathi *et al.* 2020; Jote, 2023)**. For example, cyanosis, a disease that affects children, is caused due to the excessive use of synthetic nitrogen fertilizers in agriculture and this unmanaged use results in considerable increases in concentrations of nitrates within edible plant parts (**Sarwar, 2018).**

The benefits of organic fertilizers come from their effect and functions of the organic matter content on the soil, which is ultimately reflected on the plant. After the organic matter decomposes, humus is formed, which consists of a group of hums acids (humic acid, fulvic acid and humin) with a large molecular weight that resists decomposition, meaning it is more stable... Organic fertilizers cause an increase in soil temperature and improve soil structure, thus reducing the soil bulk density. Organic fertilizers are considered a slow source of supply of many nutrients and work to protect the soil surface from erosion **(Yu *et al.* 2025).** Additionally, organic

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fertilizers improve soil health and increase biological activity and biodiversity. Therefore, the development of organic fertilizers is important as to be a promising partial alternative that reduces total reliance on synthetic fertilizers. In other words, improving the performance of organic fertilizers has become an urgent need to meet the many challenges facing the agricultural sector. The effectiveness of organic fertilizers is closely linked to their preparation method. Therefore, manufacturing processing and fermentation methods may impact their efficiency, accelerate their decomposition, and enhance their ability to release the nutrients needed by higher plants (**Singh *et al.* 2020; He *et al.* 2022)**.

Plant waste (Farm By-Products) is considered a renewable source for organic fertilizer production. Incorporating this waste into the compost manufacturing process is an effective way to dispose of it in an environmentally friendly manner, reducing pollution and transforming it into valuable agricultural inputs (**Diacono *et al.* 2019; El-Ghamry *et al.* 2019)**.

Maize (*Zea mays* L.), whose productivity is a national food security priority, is a strategic crop in Egypt. It is of significant economic and nutritional importance, plays a vital role in human and animal nutrition, and is used in many food and feed industries (**Elbeltagi *et al.* 2020)**. Therefore, this research work aims to evaluate the efficiency of a different types of compost prepared from various plant wastes (Farm By-Products) with other additives, and their suitability for improving soil health and the impact this has on vegetative growth and productivity of the maize crop. It also aims to determine their potential as a partial substitute for synthetic fertilizers to achieve sustainable and environmentally friendly production.

The research hypothesis was that improving the organic amendment by using different inputs rich in materials useful to the plant and soil might make it an ideal partial substitute for synthetic fertilizers. The aims of the current study align with the following US sustainable goals of development: SDG2 (Zero Hunger) by increasing maize productivity and food security, SDG12 (Responsible Consumption and Production): by changing organic residues into valuable products, SDG 13 (Climate Action)by decreasing synthetic fertilizers and greenhouse gas emissions, and SDG 15 (Life on Land) by increasing soil productivity and sustainability.

2. Materials and Methods

The compost piles were prepared on the soil surface at the experimental site, which is located in Meet-Anter Village, Talkha District, Dakahlia Governorate, Egypt (31°4'54"N - 31°24'4"E). The experimental soil sample was taken before sowing the maize seeds at the depth of 25.0 cm and analyzed using the standard methods described by **Gee *et al.* (1986)** and **Dewis& Freitas, (1970),** as Table 1 shows the initial physical soil properties (particle size distribution) as well as the initial chemical soil properties.

2.1. Compost mixture preparation

In this study, five types of composts were prepared as shown in Table 2. Some of the recommendations mentioned by **Misra *et al.* (2003); Inckel *et al.* (2005); El-Ghamry *et al.* 2019)** were adopted. The different types of compost were analyzed as described by **Tandon, (2005)** and their traits are shown in Table 4 (result section).

Table 1. Physical and chemical soil properties.

Characteristics	Values
Sand,%	31.0
Clay ,%	49.0
Silt,%	20.0
Textural class is Clay	
Available-N, mg kg^{-1}	39.69
Available-P, mg kg^{-1}	7.00
Available-K, mg kg^{-1}	192.3
CEC, cmol kg^{-1}	30.10
O M, %	0.90
EC, dSm^{-1}	1.97
pH in suspension (1 soil: 2.5 water)	7.92

Table 2. Method preparation of enhanced organic fertilizers.

Compost type	Method preparation
Compost$_1$	Wheat straw residues (about 600 kg) were cut into 5-10 cm lengths. A piece of plastic was spread on the ground (its area was 4.0 m^2) and plant residues were placed on it, as compost pile was formed in a pyramidal shape in homogeneous layers and each pile was about 1.5 m high. Feldspar, bentonite and phosphate rock were added at rates of 0.75 kg for each amendment. The pile was moistened with water until the moisture content reached 60%. The pile was turned every two weeks during the first two months to increase aeration and microbial activity, and left unturned during the last month. These piles were moistened daily. The temperature and humidity were measured weekly. The fermentation process continued for 12 weeks until decomposition was complete, the color turned dark brown, and the unpleasant odors disappeared.
Compost$_2$	Maize straw residues (20%leaves + 60% stalks + 20%cobs) (about 500 kg) were cut into 5-10 cm lengths. A piece of plastic was spread on the ground (its area was 4.0 m^2) and plant residues were placed on it. Additionally FYM (about 100 kg) was added, as compost pile was formed in a pyramidal shape with homogeneous layers and each pile was about 1.5 m high. Feldspar, bentonite and phosphate rock were added at rates of 0.75 kg for each amendment. The pile was moistened with water until the moisture content reached 60%. The pile was turned every two weeks during the first two months and left unturned during the last month. Water was added daily by light spraying. The temperature and humidity were measured weekly. The fermentation process continued for 12 weeks until decomposition was complete, the color turned dark brown, and the unpleasant odors disappeared.
Compost$_3$	Cotton residues (stalks) (about 600 kg) were cut in to 5-10 cm lengths. A piece of plastic was spread on the ground (its area was 4.0 m^2) and plant residues were placed on it, as compost pile was formed in a pyramidal shape with homogeneous layers and each pile was about 1.5 m high. Effective microorganisms EM (*Lactobacillus spp, Photosynthetic bacteria* and *Actinomycetes*) was dissolved in water then mixed with the cotton residues at rate of 1.5kg EM. Feldspar, bentonite and phosphate rock were added at rates of 0.75 kg for each amendment. The pile was moistened with water until the moisture content reached 60%. The pile was turned every two weeks during the first two months and left unturned during the last month. Water was added daily by light spraying. The temperature and humidity were measured weekly. The fermentation process continued for 12 weeks until decomposition was complete, the color turned dark brown, and the unpleasant odors disappeared.
Compost$_4$	Banana residues represented 65%, palm fronds 2% and wood ash 10% (about 600 kg) were cut in to 5-10 cm lengths. A piece of plastic was spread on the ground (its area was 4.0 m^2) and plant residues were placed on it, as compost pile was formed in a pyramidal shape with homogeneous layers and each pile was about 1.5 m high. Feldspar, bentonite and phosphate rock were added at rates of 0.75 kg for each amendment. The pile was moistened with water until the moisture content reached 60%. The pile was turned every two weeks during the first two months and left unturned during the last month. Water was added daily by light spraying. The temperature and humidity were measured weekly. The fermentation process continued for 12 weeks until decomposition was complete, the color turned dark brown, and the unpleasant odors disappeared.
Compost$_5$	Bean residues (about 600 kg) were cut in to 5-10 cm lengths. A piece of plastic was spread on the ground (its area was 4.0 m^2) and plant residues were placed on it, as compost pile was formed in a pyramidal shape with homogeneous layers and each pile was about 1.5 m high. Molasses was added at rate of 3.0 liter, while yeast (*Saccharomyces cerevisiae*) was dissolved in water and added to bean residues at a rate of 3.0 kg. Feldspar, bentonite and phosphate rock were added at rates of 0.75 kg for each amendment. The pile was moistened with water until the moisture content reached 60%. The pile was turned every two weeks during the first two months and left unturned during the last month. Water was added daily by light spraying. The temperature and humidity were measured weekly. The fermentation process continued for 12 weeks until decomposition was complete, the color turned dark brown, and the unpleasant odors disappeared.

2.2. Field trail

The experiment was conducted in two successive years: 2024 and 2025. Seven treatments were evaluated in this research work using the experimental completely randomized design with three replicates. The treatments were **T_1:** $Control_1$ (100% of NPK recommended dose RD as synthetic fertilizers), **T_2:** $Control_2$ (50% of NPK - RD as synthetic fertilizers), **T_3:** 50% of NPK-RD as synthetic fertilizers + $Compost_1$ (Wheat straw alone), **T_4:** 50% of NPK-RD as synthetic fertilizers + $Compost_2$ (Maize residues + FYM), **T_5:** 50% of NPK-RD as synthetic fertilizers + $Compost_3$ (Cotton stalks +microbial activator),**T_6:** 50% of NPK-RD as synthetic fertilizers + $Compost_4$ (Banana residues + palm fronds + wood ash), **T_7:** 50% of NPK-RD as synthetic fertilizers + $Compost_5$ (Bean residues + molasses + yeast). Fig1 illustrates the experimental treatments (fertilization regimes).

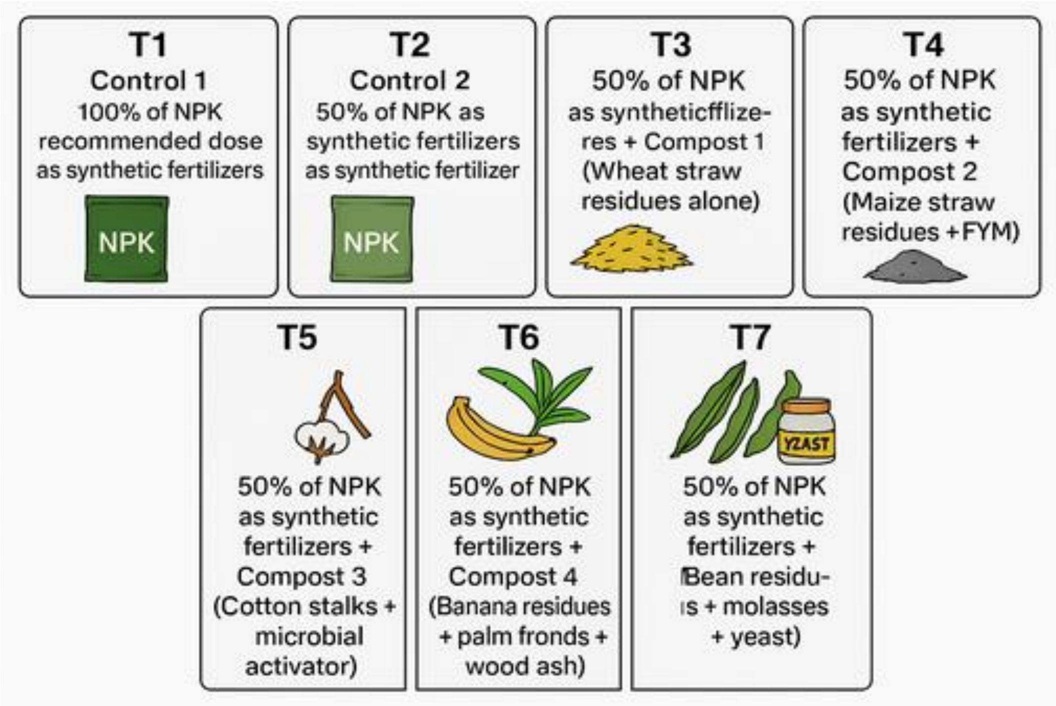

Fig. 1. Experimental treatments (fertilization regimes).

The experimental plot area was 3.0 m x 2.0 m (6.0 m^2). Seeds of an early-maturing variety (cv. Yaqout single hybrid) were sown on May 20^{th} in both studied season, where this variety is characterized by its short growth cycle allowing it to be harvested only after 90 days of sowing. Seeds were obtained from Techno Seeds Company and sown at rate of 24.0 kg ha^{-1}. All studied compost were added to the soil at a rate of 35 m^3ha^{-1} according to the studied treatments. Calcium superphosphate (6.7 % $P_)$, urea (46%N) and potassium sulphate (39.84 % K_2O) were used as NPK mineral fertilizers. The 100% of N, P and K for maize is 120, 36.6 and 95 unit of N, P and K ha^{-1} respectively as mentioned in the guidelines of the ministry of agricultural and soil reclamation (MASR). The soil was thoroughly plowed before sowing then the different types of compost, according to the studied treatments, as well as calcium superphosphate were added at the stage of soil preparation then the soil was leveled and lined with rows. Urea and potassium sulphate were added in three equal doses (according to the studied treatments) with the first, second and third irrigation events. Harvesting process took place at 90 days after sowing. Each season, some measurements were taken at two different stages, as Table 3 displays these measurements.

Table 3. Measurements during the studied stages.

Evaluation time	Evaluated traits		Methods	References
At 60 days from sowing	Plant height (cm), fresh and dry weights (gplant^{-1}) and leaf area (cm^2 plant^{-1})		Manually	--------------
	Digestion of the maize straw		Mixture of $HClO_4$ + H_2SO_4	**Peterburgski, (1968)**
	Straw chemical constitutes (NPK)		Kjeldahl for N, spectrophotometr for P (PD-303S, Japan), and flame photometer for K (PFP7, Jenway company, Türkiye)	**Walinga *et al.* (2013)**
	Photosynthetic pigments (Chlorophyll a & b and carotene pigments, mg g^{-1}) in fresh weight		Spectrophotometrically (using acetone)	**Wellburn, (1994)**
At 90 days from sowing	Grain and biological yield (ton hectare^{-1}), harvest index(%),weight of ear (g), ear length and diameter (cm), No. seeds ear^{-1} and weight of 100 grain (g)		Manually	--------------
	Seeds chemical constitutes (NPK)		As formerly mentioned in the straw.	
	Protein and carbohydrates (%)			**AOAC, (2007)**
	Soil chemical properties	Available-N, mg kg^{-1}	Kjeldahl method using K_2SO_4, (1%), devarda alloy, and H_3NSO_3, (2%)	**Dewis& Freitas, (1970)**
		Available-P, mg kg^{-1}	Olsen method *via* spectrophotometer using 0.5 M $NaHCO_3$ at a specific pH (usually around 8.5)and $SnCl_2$	
		Available-K, mg kg^{-1}	*Via* flame photometer method using $NH_4CH_3CO_2$	
		Cation exchange capacity (CEC), cmol kg^{-1}	Using $NH_4CH_3CO_2$ (pH 7.0), ethanol (95%),KCl(10%),NaOH(45%)	
		Organic matter,%	*Via* the Walkley and Black method using $K_2Cr_2O_7$, $FeSO_4$,$KMnO_4$,$H_2C_2O_4.2H_2O$ and diphenylamine indicator	
		Total microbial count (CFU g^{-1} soil)	Incubation and number of colonies grown in plates	**Wollum, (1982)**

2.3. Statistical analyses

Data statistical analysis was executed Using CoStat software using the least significant difference (LSD) test at the 0.05 probability level (Version 6.303, Copyright ,1998-2004) according to **Gómez and Gómez, (1984)** and Duncan's letters were used.

3. Results

3.1. Compost evaluation before usage

A comparison among the five types of compost was carried out before the beginning of the field experiment during the two studied seasons (Table 4). The first fertilizer (compost$_1$) had a medium weight (m^3/kg), pH was slightly alkaline, having low salinity, high content of organic carbon and low total nitrogen. Thus, its C/N ratio was high. It had a high content of organic matter. Additionally, it possessed the lowest values of phosphorus, potassium, iron, manganese, copper and zinc compared to other types of compost. The second fertilizer (compost$_2$) had a medium-high volume per unit mass of m^3 (kg), pH was neutral to slightly alkaline, having medium salinity, medium-high content of organic carbon and medium total nitrogen. Thus, its C/N ratio was balanced. It had a medium content of organic matter. Additionally it possessed medium content of phosphorus, potassium, iron, manganese, copper and zinc compared to other types of compost. The third fertilizer (compost$_3$) had a relatively high density; pH was slightly alkaline, having medium salinity, medium content of organic carbon and medium-high total nitrogen. Thus, its C/N ratio was ideal. It had a medium content of organic matter. Additionally it possessed medium content of phosphorus, potassium, iron, manganese, copper and zinc compared to other types of compost.

Table 4. The properties of different types of compost during seasons of 2024 and 2025.

Treatments	Compost$_1$		Compost$_2$		Compost$_3$		Compost$_4$		Compost$_5$	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
Weight of m^3 (kg)	500	503	540	536	635	615	550	552	545	540
pH 1:5 (1:10)	7.50	7.40	7.00	7.10	7.40	7.50	7.05	7.00	6.50	6.60
EC,dSm^{-1} (1:10)	4.00	3.87	4.30	4.25	4.35	4.40	4.95	5.15	4.40	4.60
Organic carbon,%	36.0	35.0	31.0	30.0	26.0	27.0	26.0	27.0	34.0	33.0
Total nitrogen, %	1.10	1.05	1.21	1.25	1.45	1.42	1.5	1.55	2.00	1.95
C/N ratio	32.7	33.3	25.6	24.0	17.9	19.0	17.3	17.4	17.0	16.9
Organic matter,%	61.9	60.2	53.3	51.6	44.7	46.4	43	44.72	60.2	61.92
Total potassium, %	0.50	0.6	0.8	0.70	0.9	1.0	1.8	1.85	1.30	1.32
Total phosphorus,%	0.30	0.25	0.6	0.55	0.8	0.9	1.1	1.15	1.50	1.40
Iron, mg kg^{-1}	0.50	0.66	0.70	0.82	0.99	1.15	1.25	1.34	1.88	1.80
Manganese, mg kg^{-1}	78.8	80.2	100	102.2	105	108	109	113	120	118
Copper , mg kg^{-1}	102	99.5	116	117	122	120	165	162	200	189
Zinc, mg kg^{-1}	21.5	22.0	22.9	23.2	24.3	24.0	25.6	27.3	28.0	30.0

Notes: Compost$_1$ (Wheat straw alone)
Compost$_2$ (Maize residues + FYM)
Compost$_3$ (Cotton stalks +microbial activator)
Compost$_4$ (Banana residues + palm fronds + wood ash)
Compost$_5$ (Bean residues + molasses + yeast)

The fourth fertilizer (compost$_4$) had a medium weight of m^3 (kg), pH was neutral to alkaline, having medium-high salinity, medium content of organic carbon and low-medium total nitrogen. Thus, its C/N ratio was ideal. It had a medium content of organic matter. Additionally it possessed medium- high content of phosphorus, iron, manganese, copper and zinc compared to other types of compost. Moreover, it had a highest content of potassium. The fifth fertilizer (compost$_5$) had a medium weight of m^3 (kg), pH was neutral to slightly acidic, having medium salinity, high content of organic carbon and total nitrogen. Thus, its C/N ratio was ideal. It had a high content of organic matter. Additionally it possessed high content of phosphorus, potassium, iron, manganese, copper and zinc compared to other types of compost. There was a great convergence in properties of each compost type in both seasons, reflecting a relative stability in the method of preparation and the quality of the raw materials entering into the composition. That is, following the same preparation approach in the second season resulted in the production of organic fertilizers that were somewhat similar in their properties to the organic fertilizers produced in the first season.

3.2. Plant performance at 60 and 90 days

The studied treatments significantly affected plant performance at 60 days from sowing, including growth criteria (Plant height fresh and dry weights and leaf area), straw chemical constituents (NPK) and photosynthetic pigments (chlorophyll a & b and carotene) at 60 days from sowing during both studied seasons **(Tables 5, 6 and 7).** Also, the studied treatments significantly affected yield and its component at harvest stage, including grain and biological yield, harvest index, weight of ear, ear length and diameter, No. seeds ear^{-1}, weight of 100 grain and ear quality (N, P, K, protein and carbohydrates) **(Tables 8, 9 and 10).**

Table 5. Impact of the studied fertilization regimes on maize growth criteria at 60 days from sowing during seasons of 2024 and 2025.

Treatments	Plant height, cm		Fresh weight, g plant^{-1}		Dry weight, g plant^{-1}		Leaf area, cm^2 plant^{-1}	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	224.9ab	234.3ab	839.9c	853.1c	270.8b	274.8b	591.2cd	603.0cd
T_2	209.9d	218.8d	803.6d	815.7e	246.1d	249.5d	564.8f	574.4f
T_3	217.1c	225.8c	818.6cd	828.5de	249.7cd	253.6cd	571.3ef	583.0ef
T_4	219.8bc	229.9bc	824.0cd	836.9cd	254.6c	257.9c	580.0de	592.2de
T_5	227.40a	236.5a	881.2b	892.3b	276.9b	280.4b	597.8bc	609.4bc
T_6	227.6a	236.5a	882.7b	895.4b	288.8a	292.9a	612.1ab	623.6ab
T_7	229.6a	238.3a	911.5a	924.0a	291.7a	295.8a	614.0a	625.4a
F. test	**	**	**	**	**	**	**	**
LSD at 5%	**5.67**	**5.36**	**21.81**	**19.95**	**6.99**	**6.18**	**15.00**	**15.06**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T1: Control1 (100% of NPK recommended dose RD as synthetic fertilizers), T2: Control2 (50% of NPK - RD as synthetic fertilizers), T3: 50% of NPK-RD as synthetic fertilizers + Compost1 (Wheat straw alone), T4: 50% of NPK-RD as synthetic fertilizers + Compost2 (Maize residues + FYM), T5: 50% of NPK-RD as synthetic fertilizers + Compost 3 (Cotton stalks +microbial activator),T6: 50% of NPK-RD as synthetic fertilizers + Compost 4 (Banana residues + palm fronds + wood ash), T7: 50% of NPK-RD as synthetic fertilizers + Compost 5 (Bean residues + molasses + yeast)

Table 6. Impact of the studied fertilization regimes on chemical constituents in leaf of maize at 60 days from sowing during seasons of 2024 and 2025.

Treatments	Nitrogen, %		Phosphorus, %		Potassium, %	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	3.25c	3.30b	0.345c	0.349bc	4.02b	4.08ab
T_2	2.95d	2.99c	0.314e	0.320d	3.81d	3.87c
T_3	2.97d	3.02c	0.320e	0.327d	3.89c	3.94bc
T_4	3.19c	3.24b	0.334d	0.343c	3.90c	3.96bc
T_5	3.33b	3.39ab	0.347bc	0.355b	3.99b	4.06ab
T_6	3.35b	3.42ab	0.356b	0.367a	4.12a	4.19a
T_7	3.50a	3.58a	0.367a	0.375a	4.16a	4.22a
F. test	**	**	**	**	**	**
LSD at 5%	**0.08**	**0.19**	**0.009**	**0.009**	**0.07**	**0.18**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), T_2: Control$_2$ (50% of NPK - RD as synthetic fertilizers), T_3: 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), T_4: 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), T_5: 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),T_6: 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), T_7: 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

Table 7. Impact of the studied fertilization regimes on photosynthetic pigments content in leaf of maize at 60 days from sowing during seasons of 2024 and 2025.

Treatments	Chlorophyll a, mg g^{-1}		Chlorophyll b, mg g^{-1}		Carotene, mg g^{-1}	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	1.03b	1.06b	0.678b	0.699b	0.441c	0.455c
T_2	0.92d	0.95d	0.633d	0.646d	0.410e	0.421e
T_3	0.94cd	0.96cd	0.638cd	0.658cd	0.419e	0.432d
T_4	0.96c	0.97c	0.654c	0.667c	0.430d	0.439d
T_5	1.04b	1.06b	0.693ab	0.708ab	0.447c	0.457c
T_6	1.05ab	1.08ab	0.698a	0.719a	0.458b	0.469b
T_7	1.07a	1.09a	0.705a	0.719a	0.468a	0.477a
F. test	**	**	**	**	**	**
LSD at 5%	**0.025**	**0.023**	**0.017**	**0.012**	**0.008**	**0.008**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T1: Control1 (100% of NPK recommended dose RD as synthetic fertilizers), T2: Control2 (50% of NPK - RD as synthetic fertilizers), T3: 50% of NPK-RD as synthetic fertilizers + Compost1 (Wheat straw alone), T4: 50% of NPK-RD as synthetic fertilizers + Compost2 (Maize residues + FYM), T5: 50% of NPK-RD as synthetic fertilizers + Compost 3 (Cotton stalks +microbial activator),T6: 50% of NPK-RD as synthetic fertilizers + Compost 4 (Banana residues + palm fronds + wood ash), T7: 50% of NPK-RD as synthetic fertilizers + Compost 5 (Bean residues + molasses + yeast)

Table 8. Impact of the studied fertilization regimes on the yield of maize at 90 days from sowing during seasons of 2024 and 2025.

Treatments	Grain yield, ton hectare^{-1}		Biological yield, ton hectare^{-1}		Harvest index, %	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	6.27b	6.39b	10.7b	10.9b	0.59a	0.59a
T_2	4.88e	4.97e	9.7d	9.9d	0.50c	0.50c
T_3	5.36d	5.47d	9.8d	10.1cd	0.54b	0.54b
T_4	5.87c	6.00c	10.1c	10.3c	0.58a	0.58a
T_5	6.37b	6.49b	10.9a	11.1ab	0.58a	0.58a
T_6	6.40ab	6.52b	11.0a	11.3a	0.58a	0.58a
T_7	6.55a	6.68a	11.1a	11.4a	0.59a	0.59a
F. test	**	**	**	**	*	*
LSD at 5%	0.15	0.16	0.20	0.27	0.02	0.02

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), T_2: Control$_2$ (50% of NPK - RD as synthetic fertilizers), T_3: 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), T_4: 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), T_5: 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),T_6: 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), T_7: 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

Table 9. Impact of the studied fertilization regimes on the yield components of maize at 90 days from sowing during seasons of 2024 and 2025.

Treatments	Weight of ear, g		Ear length, cm		Ear diameter, cm		No. seeds ear^{-1}		Weight of 100 grain, g	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	224.7d	229.4d	18.97d	19.29d	3.89b	3.96b	347.6b	351.6b	42.6ab	43.4bc
T_2	169.4f	173.2f	17.32g	17.58g	2.74e	2.79d	277.6d	281.5d	38.4c	38.9e
T_3	173.8f	177.5f	17.84f	18.12f	3.43d	3.51c	286.6c	289.8cd	38.8c	39.4d
T_4	179.3e	183.4e	18.34e	18.69e	3.57c	3.66c	291.6c	296.1c	42.5b	43.1c
T_5	232.3c	237.8c	19.78c	20.16c	3.85b	3.94b	351.6b	355.3b	43.9ab	44.1b
T_6	239.7b	244.7b	21.48b	21.91b	3.86b	3.94b	365.0a	368.9a	42.7ab	43.6a
T_7	245.6a	252.2a	22.81a	23.24a	4.16a	4.28a	368.6a	373.3a	43.6a	44.1a
F. test	**	**	**	**	**	**	**	**	**	**
LSD at 5%	5.24	5.25	0.49	0.53	0.09	0.22	6.49	8.95	1.04	0.31

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), T_2: Control$_2$ (50% of NPK - RD as synthetic fertilizers), T_3: 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), T_4: 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), T_5: 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),T_6: 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), T_7: 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

Table 10. Impact of the studied fertilization regimes on the quality of maize at 90 days from sowing during seasons of 2024 and 2025.

Treatments	Nitrogen, %		Phosphorus, %		Potassium, %		Protein, %		Carbohydrates, %	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
T_1	1.69b	1.75b	0.216c	0.222b	2.67b	2.76bc	9.69b	10.10b	68.7cd	70.1c
T_2	1.42d	1.47d	0.196e	0.201d	2.26c	2.32d	8.15d	8.48d	65.766e	66.9d
T_3	1.51cd	1.56cd	0.198e	0.204d	2.29c	2.34d	8.69cd	9.02cd	67.2de	68.7cd
T_4	1.56c	1.63c	0.205d	0.209c	2.64b	2.73c	8.98c	9.40c	68.3cd	69.8c
T_5	1.78ab	1.84ab	0.220b	0.224b	2.70b	2.78bc	10.2ab	10.6ab	69.1bc	70.4bc
T_6	1.83b	1.89a	0.226a	0.232a	2.74b	2.83b	10.5a	10.9a	70.6ab	72.0ab
T_7	1.84a	1.90a	0.227a	0.232a	2.86a	2.95a	10.6a	11.0a	70.0a	72.3a
F. test	*	**	**	**	*	**	**	**	**	**
LSD at 5%	0.10	0.10	0.004	0.004	0.10	0.08	0.60	0.60	1.60	1.78

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), T_2: Control$_2$ (50% of NPK - RD as synthetic fertilizers), T_3: 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), T_4: 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), T_5: 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),T_6: 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), T_7: 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

The superior treatment was T_7 treatment [50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)**]**, which achieved the highest values of growth criteria, straw chemical constituents (NPK), photosynthetic pigments and ear qualitative and quantitative traits. The T_6 treatment **[**50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash)] came in the second order in terms of effectiveness followed by T_5 treatment [50% of NPK-RD as synthetic fertilizers + (Cotton stalks +microbial activator)], then T_1, T_4, T_3 and T_2, respectively. It is worth noting that the T_1 treatment (100% of NPK recommended dose RD as synthetic fertilizers) came in the middle of the ranking compared to the other treatments. This provides a strong indication that there are types of the studied compost that can serve as a partial substitute for synthetic fertilizers without significantly affecting performance and productivity.

3.3. Soil properties at harvest

Treatments from T_3 to T_4 significantly impacted the soil properties at harvest stage such as available nitrogen , phosphorus and potassium, CEC and organic matter (Table 11), all types of compost positively affected on these properties, the superior treatment, which recorded the highest values of all aforementioned traits, was T_7 treatment [50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)**]** followed by T_6 treatment **[**50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash)] then T_5 treatment [50% of NPK-RD as synthetic fertilizers + (Cotton stalks +microbial activator)], T_4 treatment [50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM)] and T_3 treatment [50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone)], respectively. In other words, the order sequence from top effectives to less were$T_7 > T_6 > T_5 > T_4 > T_3 > T_2 > T_1$.

Table 11. Impact of the studied fertilization regimes on the chemical soil properties after maize harvest (at 90 days from sowing) during seasons of 2024 and 2025.

Treatments	Available-N, mg kg^{-1}		Available-P, mg kg^{-1}		Available-K, mg kg^{-1}		CEC, cmol kg^{-1}		O M, %	
	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season	1st Season	2nd season
Initial soil	39.69	40.1	7.00	7.15	192.3	197.6	30.10	31.06	0.90	0.94
T_1	39.9d	40.3d	9.7d	9.90e	195.9f	198.9d	30.08f	31.09f	0.99e	0.94e
T_2	39.9d	40.3d	7.06e	7.26f	195.1g	198.2d	30.13f	31.09f	1.01e	0.96e
T_3	40.1cd	40.6cd	9.5c	9.66d	198.7e	201.6cd	32.73e	33.7de	1.21d	1.25d
T_4	40.8bc	41.4bc	9.9b	10.2c	199.7d	202.9bc	33.68d	34.65d	1.32c	1.36c
T_5	41.1b	41.6bc	10.0b	10.2b	202.2c	205.4b	35.71c	36.68c	1.44b	1.48bc
T_6	41.5ab	42.0ab	10.4a	10.6a	206.0b	210.5a	36.53b	37.91b	1.48b	1.53b
T_7	42.2a	42.8a	10.4a	10.6a	208.0a	210.8a	37.60a	38.98a	1.53a	1.58a
F. test	**	**	**	**	**	**	**	**	**	**
LSD at 5%	**0.81**	**1.04**	**0.17**	**0.03**	**0.42**	**3.96**	**0.10**	**0.89**	**0.05**	**0.05**

Means within a row followed by a different letter (s) are statistically different at a 0.05 level
T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), T_2: Control$_2$ (50% of NPK - RD as synthetic fertilizers), T_3: 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), T_4: 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), T_5: 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),T_6: 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), T_7: 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

3.4. Soil health at harvest

Total microbial count (CFU g^{-1} soil) at harvest in the soil at harvest during seasons of 2024 and 2025 was significantly affected (Fig 2), as the highest values were achieved with the T_7 treatment followed by T_6 treatment then T_5,T_4, T_3, respectively.**T_2 and T_1** treatments (50 and 100% of NPK-RD as synthetic fertilizers) recorded the lowest values of Total microbial count (CFU g^{-1} soil) at harvest in the soil at harvest during seasons of 2024 and 2025.

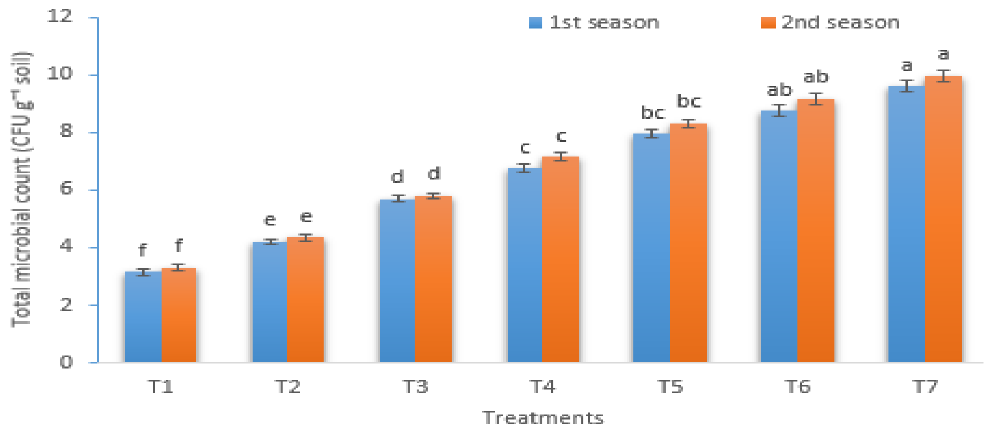

Fig. 2. Impact of the studied fertilization regimes on total microbial count (CFU g^{-1} soil) at harvest in soil during seasons of 2024 and 2025.

T_1: Control$_1$ (100% of NPK recommended dose RD as synthetic fertilizers), **T_2:** Control$_2$ (50% of NPK - RD as synthetic fertilizers), **T_3:** 50% of NPK-RD as synthetic fertilizers + Compost$_1$ (Wheat straw alone), **T_4:** 50% of NPK-RD as synthetic fertilizers + Compost$_2$ (Maize residues + FYM), **T_5:** 50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator),**T_6:** 50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash), **T_7:** 50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)

4. Discussion

The obtained results confirmed that all treatments that included compost **(T_3,T_4,T_5,T_6,T_7)** significantly improved soil properties compared to treatments that did not contain compost **(T_1,T_2).** All of them **(T_3,T_4,T_5,T_6,T_7)** may have increased the organic content in the soil, which may have led to higher CEC values and possibly also increased the soil's WHC (**Carter & Bentley, 2016**). Furthermore, all treatments that contained compost may have improved the soil's structural composition, which improved root aeration. They may also have increased microbial activity in the root zone, resulting in faster decomposition rates and conversion of elements from organic matter to a form readily available to the growing maize. Compost (all used types) also may have played a role in lowering the soil pH, hence raising the nutrient availability, which also facilitated its absorption (**Mitchell *et al.* (2025)**.The results indicate that compost$_5$ was the superior type, followed by compost$_4$, then compost$_3$, then compost$_2$, and finally compost$_1$ in improving soil properties. This can be explained based on the composition of each type and the nature of its organic and mineral components.

Compost$_5$ clearly outperformed due to its high contents of rapidly decomposable organic matter such as molasses, in addition to the high microbial activity due to the use of yeast, which increased decomposition rates and facilitated the release of nutrients to the growing maize as well as this organic matter in compost$_5$ also stimulated the activities of soil biota that took part in organic matter decomposition. Molasses is a rich source of easily decomposed carbon and sugars, which quickly provides beneficial organisms with energy, increasing their activity and accelerating the decomposition of organic matter **(Meng *et al.* 2020).** All of this positively affects the nutritional value of the resulting compost. As for the yeast used, it is a source of proteins, vitamins, and growth stimulants. Therefore, when added to the compost pile, it improves the growth of beneficial organisms and enhances their diversity, as it increases nitrogen-fixing bacteria and phosphorus-solubilizing bacteria (**Nakasaki & Hirai, 2017).** Moreover, the bean residues used in this compost is also known for its richness in nitrogen, which positively influenced soil fertility and health, as well as the initial growth of the higher plant (**El-Ghamry *et al.* 2019).**

Compost$_4$ also achieved good results due to the banana residues, palm fronds and wood ash, which were used in this compost. Therefore, it contained a high content of potassium and structural materials, which may have improved soil structure and aeration. The ash also may have provided nutrients such as calcium and magnesium. Ash contains high levels of nutrients such as magnesium, calcium, potassium and phosphorus, which enhance the nutritional value of the resulting compost (**Mupambwa *et al.* 2015)**. Banana residues are a rich source of potassium, as well as carbohydrates and other easily decomposed organic compounds (**Abro *et al.* 2019)**. Palm fronds are rich in fiber and cellulose and may provide a favorable environment for aerating the compost pile and improving its structure (**Sabiani & Awang, 2022)**. This may help regulate moisture and prevent clumping in the pile. This synergistic effect may have contributed to the production of superior compost. Composts $_{3,\ 2,\ 1}$ ranked lower, perhaps due to their shortage of microbial stimulants or perhaps due to their lake of components rich in macro- and micronutrients, or perhaps because they contained less decomposed organic matter than other compost types. Consequently, their effectiveness in improving soil properties and growing maize performance was relatively limited compared to $compost_5$ and $compost_4$.

Regarding maize performance during the two study stages, **T_7** treatment (50% of NPK-RD as synthetic fertilizers + $Compost_5$ (Bean residues + molasses + yeast) showed the best performance in vegetative growth and production. This is due to the integration between organic and synthetic fertilizers **(El-Bialy *et al.* 2025).** The type of compost in this treatment likely provided nutrients on a continuous and long-term basis. Conversely, 50% mineral fertilizer may have provided a rapid boost of nutrients in the early stages of growth. In other words, this integration led to an ideal nutritional balance, stimulated root activity and growth, and increased nutrient uptake, which positively affected maize growth and productivity.

On the other hand, it can be noticed that **T_5,T_6 and T_7** treatments outperformed **T_1** treatment (100% of NPK recommended dose RD as synthetic fertilizers), which may be due to the improvement in the physical and chemical circumstances of the soil in the presence of compost, compared to presence the synthetic fertilizers alone, which may have led to salt accumulation over time. Moreover, the gradual availability of nutrient elements from the compost different types may have prevented nutrient loss, especially nitrogen, *via* volatilization or leaching compared to the synthetic fertilizers. Also, the superiority of **T_5,T_6** and **T_7** treatments over the **T_1** treatment (100% of NPK recommended dose RD as synthetic fertilizers) may be due to the fact that all types of compost studied may have contained growth-stimulating compounds, such as compounds that encourage microbial activity, which is what synthetic fertilizers lack.

The increase in microbial counts due to the studied treatments containing compost indicates microbial activity in the soil due to organic additives **(T_3, T_4, T_5, T_6, T_7),** which is an indicator of improved soil health and properties. **T_1** Treatment (100% of NPK recommended dose RD as synthetic fertilizers) recorded the lowest microbial counts values and this due to the lack of the available organic matter to organisms, which negatively affects the reproduction and growth of these organisms. Furthermore, synthetic fertilizers may have caused a toxic effect on beneficial soil organisms. Similarly, **T_2** treatment (50% of NPK recommended dose RD as synthetic fertilizers) performed similarly. Although it recorded a higher microbial count than the **T_1** treatment, this was due to the reduced dose of synthetic fertilizer, which reduced the chemical pressure on soil microorganisms. However, it still did not provide a sufficient carbon source to support the microorganism growth. **T_3** treatment [50% of NPK-RD as synthetic fertilizers + $Compost_1$ (Wheat straw alone)] and **T_4** treatment [50% of NPK-RD as synthetic fertilizers + $Compost_2$ (Maize residues + FYM)] resulted in a significant increase in microbial counts because the plant residues used serve as a rich source of carbon and organic matter, which led to significant microorganism activity. Furthermore, the addition of FYM to **T_4** treatment made it superior to **T_3** treatment, possibly because the FYM may have contained the beneficial microorganisms. **T_5** treatment [50% of NPK-RD as synthetic fertilizers + $Compost_3$ (Cotton stalks +microbial activator)] resulted in a higher microbial count compared to previous treatments **(T_1, T_2, T_3, T_4)**, possibly due to the use of a microbial activator with the cotton residues, which significantly stimulated microbial communities and stimulated their growth. Meanwhile, **T_6** treatment [50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash)] recorded a higher microbial count than T_5 treatment, possibly due to the presence of diverse organic components, such as banana waste and palm fronds in the **T_6** treatment, which provided nutritional diversity that nourished different groups of microorganisms. Furthermore, the ash used in composting may have contributed to an improved microbial growth environment due to its mineral content. **T_7** treatment [50% of NPK-RD as synthetic fertilizers + Compost $_5$ (Bean residues + molasses + yeast)] achieved the highest microbial count, as the components of this treatment significantly enhanced the proliferation of beneficial organisms and helped improve the soil's biological environment. This mixture provided an ideal blend of simple and complex carbon sources. In addition, molasses and yeast were strong stimulants of microbial activity, and bean waste is rich in nitrogen and organic nutrients. The obtained results are in harmony with those of **Diacono *et al.* (2019); El-Ghamry *et al.* (2019); Singh *et al.* (2020); He *et al.* (2022)**.

5. Conclusion

The obtained results confirm that using 50% of NPK-RD as synthetic fertilizers + $Compost_5$ (Bean residues + molasses + yeast) achieved the highest increases in plant growth criteria, straw chemical constituents, photosynthetic pigments and ear qualitative and quantitative traits. Many other combined synthetic fertilizers + Compost treatments such as **T_5** [50% of NPK-RD as synthetic fertilizers + Compost $_3$ (Cotton stalks +microbial activator) and **T_6** [50% of NPK-RD as synthetic fertilizers + Compost $_4$ (Banana residues + palm fronds + wood ash)], recorded superior impacts on soil productivity versus the reference control, 100% of NPK recommended dose RD. This provides a strong indication that there are types of the studied compost that can serve as a partial substitute for synthetic fertilizers without significantly affecting plant performance and soil productivity. Generally, it can be recommended to use compost $_{5,4,3}$, in conjunction with a reduction of Synthetic fertilizers by up to 50% as part of integrated plant nutrition management programs, as this approach achieves high productivity and lower costs. Furthermore, this approach represents a fundamental step toward reducing reliance on expensive synthetic fertilizers with negative environmental influences.

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Author contribution:

Shimaa M. Elmahdy participated in manuscript revision and contributed to writing specific sections**.**

Hassan El-Ramady contributing to the development of the scientific methodology, provided critical scientific review and performed language editing.

Mohamed A. El-Sherpiny Conducting the field experiments and preparing the materials used **.**

Dina A. Ghazi conducted the statistical analyses and supported the field implementation

All authors contributed equally to the design and implementation of the research and approved the final version of the manuscript.

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