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Integrated Organic and Inorganic Amendments for Improving Productivity of Okra (*Abelmoschus esculentus* L.) in Alkaline Soil

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SALINITY and alkaline stress pose major constraints for crop production. The use of soil amendments can help alleviate salinity and alkaline stress and improve productivity in salt-affected soils. A field experiment was conducted in 2021 and 2022 in Damietta, Egypt, to evaluate the effect of different organic and inorganic amendments on the growth, yield, quality, and nutrient uptake of okra (*Abelmoschus esculentus* L. cv. Balady) grown in alkaline soil. Treatments included gypsum (GP), organic matter (poultry manure; OM), fulvic acid (FA), humic acid (HA), and their combinations. The application of humic acid + organic matter + gypsum resulted in the tallest plants, the highest number of leaves, the greatest leaf area, the maximum pod yield, and increased nutrient uptake over control. It also gave the highest marketable yield, which was over 100% greater than control. The organic and inorganic amendments caused an appreciable improvement in soil properties like pH, EC, CEC and ESP. The results demonstrated that the integrated application of humic acid, organic matter, and gypsum could effectively reclaim the alkaline soil and improve the growth, yield, and nutritional quality of okra. The synergistic effects of the amendments in enhancing soil physical, chemical, and biological properties led to better plant growth and productivity under salinity stress conditions. The use of organic residues also helped sustain soil health. Despite greater amendment costs, HA+OM+GP had higher incremental yields (108–112%) over the farmer's practice of applying only organic matter and attractive returns on investment. The study showed that a holistic approach combining organic and inorganic amendments was most effective for okra cultivation in problematic soils.

Keywords: Humic substances, organic manure, gypsum, poultry manure, soil properties.

1. Introduction

Using soil amendments is an effective strategy for reclaiming sodic soils and improving crop productivity in such problematic soils (Alcívar et al., 2018; Gangwar et al., 2020; Leogrande & Vitti, 2019). Organic amendments like poultry manure, compost, and vermicompost can improve the physical, chemical, and biological properties of salt-affected soils (Diacono & Montemurro, 2015; Leogrande & Vitti, 2019). Inorganic amendments like gypsum [$CaSO_4 \cdot 2H_2O$] can replace exchangeable Na^+ with Ca^{2+}, thereby improving soil structure and leaching of excess salts (Bello et al., 2021; Rai et al., 2021; Sahakyan et al., 2022). Humic substances such as humic and fulvic acids also alleviate salt stress in plants by direct and indirect mechanisms (Akladious & Mohamed, 2018; Canellas et al., 2015; Ouni et al., 2014). Integrated use of organic and inorganic amendments is more effective for reclamation and sustainable productivity of salt-affected soils (Kaledhonkar et al., 2019; Kumar et al., 2022).

Alkaline soil has a high pH, usually greater than 8.5. These soils contain high levels of exchangeable sodium, which results in poor structure. This reduces water infiltration and aeration. Alkaline soils cover a large global area and pose major constraints for crop production. Saline soil has excess soluble salts, including chlorides and sulphates of Na, Mg, and Ca. Salinity causes both osmotic and ionic stress in plants. The main difference is that saline soils are dominated by neutral soluble salts while alkaline soils have excess Na ions that degrade structure (Gupta et al., 2019).

Okra (*Abelmoschus esculentus* L.) is an important vegetable crop grown in tropical and subtropical regions of the world. It is valued for its nutritious pods containing vitamins, minerals, proteins, carbohydrates, and dietary fiber (Elkhalifa et al., 2021; Singh et al., 2014). Okra can be grown on a range of soil type, but sodic soils often pose problems for its cultivation. These soils contain excess sodium salts that degrade the soil structure, affect water infiltration and drainage, and create nutritional

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imbalances that inhibit plant growth (Hailu & Mehari, 2021; Machado & Serralheiro, 2017). Soil salinity stress disrupts physiological and biochemical processes in plants, resulting in reduced germination, growth, and yield (Arif et al., 2020; Shahid et al., 2020).

Such studies are lacking for okra grown in alkaline soils. Therefore, the present study was aimed at evaluating the effect of different organic and inorganic soil amendments on the growth, yield, and nutritional quality of okra and the properties of an alkaline soil.

2. Materials and Methods

2.1. Experimental Site Description

The field experiment was conducted during two growing seasons (2021 and 2022) at a private farm in Damietta Governorate, Egypt. The mean and standard deviation of various climatic factors including precipitation, relative humidity, specific humidity, surface pressure, and maximum and minimum wind speeds during the okra cultivar growing seasons in 2021 and 2022 at the experimental site (Table 1). The climatic data recorded during the 2021 and 2022 growing seasons indicates that the climate of the experimental site can be described as hot and dry in the summer. Maximum temperatures during the summer months (June-July) were high, ranging between 30-40°C, while minimum temperatures dropped to around 20-25°C. It is noted that there was a complete lack of rainfall during the summer, indicating the dry nature of the climate (Fig. 1). Average relative humidity values were moderate (65-75%), with a slight increase in specific humidity in the summer due to higher temperatures. Wind speed was generally low, with a maximum recorded wind speed of 5.8 m/s in April 2021 (Fig. 1). Regarding soil moisture, drying of the surface soil layer and root zone was observed during the summer, with a noticeable decrease in moisture at 50 cm depth as well (Fig. 2). These prevailing climatic conditions during the study seasons indicate that the site is in semi-arid areas with a hot, dry summer climate and moderate winters. The soil at the experimental site was alkaline in reaction with poor fertility status (Table 2).

2.2. Experimental Design and Treatments

The experiment was laid out in a randomized complete block design with three replications. The seven soil amendment treatments evaluated were: control, gypsum (GP), organic matter (poultry manure; OM), fulvic acid (FA), humic acid (HA), OM + GP, and FA + OM + GP. Gypsum and organic matter were incorporated during soil preparation at 9.5 t ha^{-1} and 95.5 m^3 ha^{-1}, respectively. This gypsum quantity was estimated based on the exchangeable sodium percentage (ESP) value and the soil pH, as it is an alkaline soil, and the acidity level needs to be lowered. The high ESP value indicates the presence of high exchangeable sodium levels, which requires adding enormous amounts of gypsum to replace the sodium with calcium and improve the soil properties. The chemical composition of the organic amendment is presented in Table 2. Fulvic acid and humic acid were applied as soil application at 35 days after sowing and at first tillage at 625 kg ha^{-1}. Each plot was 5 m long and had 4- ridges spaced 60 cm apart and 70 cm wide. The net plot size was 50 m^2.

2.3. Crop Husbandry

Okra (*Abelmoschus esculentus* L. cv. Balady) seeds were planted on 1 April 2021 and 5 April 2022 at a spacing of 20 cm between plants and 50 cm between rows. Recommended agronomic practices for okra cultivation were followed during cropping. The irrigation system employed for the okra crop follows surface irrigation methods according to standard agricultural practices for okra cultivation. Weeding was done manually at 20 and 40 days after sowing. Insect pests were controlled by spraying recommended plant protection chemicals. Nitrogen, phosphorus and potassium were applied at 90 kg N ha^{-1}, 26.16 kg P ha^{-1} and 39.67 kg K ha^{-1} as per the recommendations for okra.

2.4. Data Collection

Okra pods were harvested manually by picking every 3-4 days, beginning 70 days after sowing. The total yield was recorded for each treatment and graded into marketable and unmarketable categories. Plant samples were collected at 90 days after sowing for analysis of nitrogen, phosphorus, and potassium concentrations.

Initial soil samples were collected before imposing the treatments on the surface layer (0-30 cm) and analysed for relevant physico-chemical properties (Table 3). Post-harvest soil sampling was done likewise to determine the effect of treatments on soil properties. Soil organic matter was determined following the Walkley-Black method. Electrical conductivity and pH were measured in soil-water (1:5) extraction and (1:2.5) suspension, respectively. The available nitrogen (N) was extracted using KCl and estimated following the micro-Kjeldahl distillation method. Available P was extracted using Olsen's reagent and determined colorimetrically. Exchangeable potassium (K) was extracted using ammonium acetate and measured using a flame photometer (Sparks et al., 2020). Particle size distribution was analysed using the hydrometer method (Dane & Topp, 2020).

Plant samples were analysed for N, P and K concentrations after wet digestion with sulfuric acid-hydrogen peroxide (Wolf, 1982). Nitrogen was estimated by the micro-Kjeldahl distillation method. Phosphorus was determined colorimetrically, and potassium by flame photometer. Nutrient uptake was computed from the yield and nutrient concentrations.

2.5. Economic Analysis

The economic analysis was conducted based on marketable yield, prevailing local market prices for okra and amendments, variable input costs, and simple financial indicators like gross return, net return and benefit-cost ratio. Marketable okra yield (kg/ha) for each treatment was obtained from the field study results. The farmgate price of okra was taken as 20 Egyptian pounds (LE)/kg based on local commercial price. Prices of amendments including gypsum, poultry manure, fulvic acid and humic acid were obtained from local agricultural input suppliers and expressed on a per unit basis (LE t^{-1}, LE kg^{-1} or LE m^{-3}). Amendment application rates (t ha^{-1}, kg ha^{-1} or m^3 ha^{-1}) for each treatment were used along with unit prices to compute amendment costs (LE ha^{-1}). Total variable costs (LE ha^{-1}) covered expenses on tillage, sowing, fertilizer, irrigation, weeding and plant protection chemicals, with costs equally distributed across all treatments. Gross return was calculated by multiplying marketable yield and okra price. Net return (LE ha^{-1}) was worked out by deducting total variable costs from gross income. Benefit-cost ratio was determined as a ratio of gross return to total variable cost.

2.6. Statistical Analysis

The data were statistically analysed using analysis of variance technique by SPSS (v. 24, IBM Inc., Chicago, II, USA). Mean values were compared using Tukey's HSD test at 5% level of significance (Steel, 1997).

Table 1. Average Precipitation (mm day^{-1}), Relative Humidity (%), Specific Humidity (g kg^{-1}) Surface Pressure (kPa), Maximum Wind Speed (m s^{-1}) and Minimum Wind Speed (m s^{-1}) of the experimental site during cultivar seasons 2021 and 2022.

Date		Precipitation Corrected (mm day^{-1})		Relative Humidity (%)		Specific Humidity (g kg^{-1})		Surface Pressure (kPa)		Wind Speed Maximum (m s^{-1})		Wind Speed Minimum (m s^{-1})	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
2021	April	0.042	0.111	68.434	5.396	9.034	1.459	101.603	0.345	5.798	1.587	2.799	1.406
	May	0.000	0.000	66.231	4.456	11.683	0.796	101.228	0.165	5.625	0.866	2.126	1.196
	June	0.000	0.000	67.357	3.809	13.231	1.806	101.213	0.260	5.505	0.729	2.370	1.117
	July	0.000	0.000	68.010	3.285	15.920	0.806	100.701	0.176	5.865	0.984	2.896	1.212
2022	April	0.000	0.000	73.206	7.179	9.743	1.025	101.235	0.314	5.738	1.479	2.470	1.165
	May	0.000	0.000	71.037	4.985	11.530	1.481	101.337	0.268	6.210	1.616	2.661	1.490
	June	0.000	0.000	69.223	3.819	14.250	0.749	100.905	0.131	5.551	0.761	2.448	1.167
	July	0.010	0.036	67.437	4.191	15.457	1.155	100.683	0.132	5.452	0.798	2.726	0.941

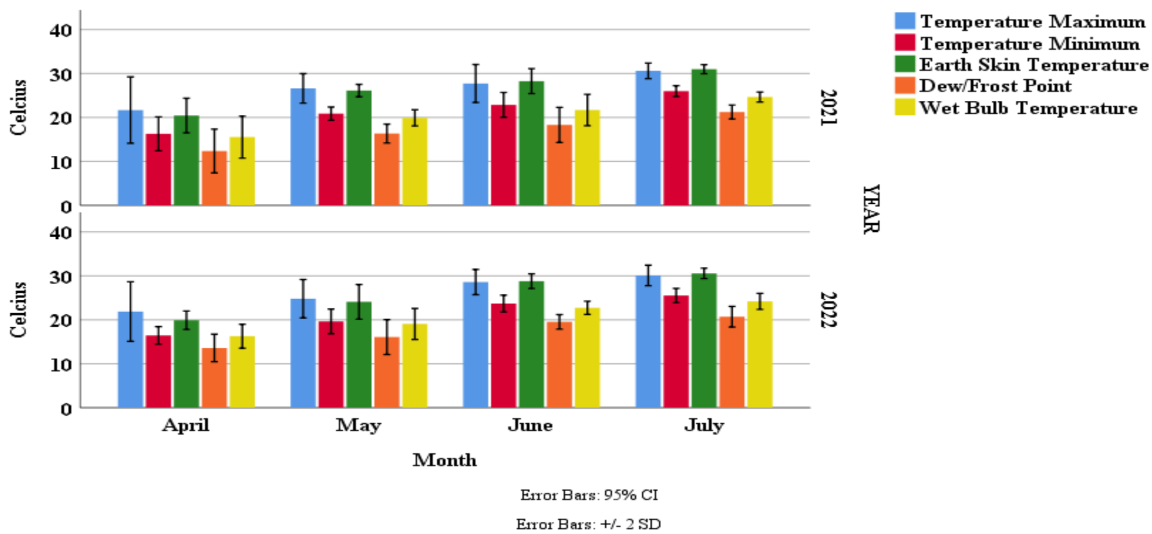


Fig. 1. Maximum and Minimum Temperature, Earth Skin Temperature, Dew/Forest Point, Wet Bulb and Earth Skin Temperature (°C) of the experimental site during cultivar seasons 2021 and 2022.

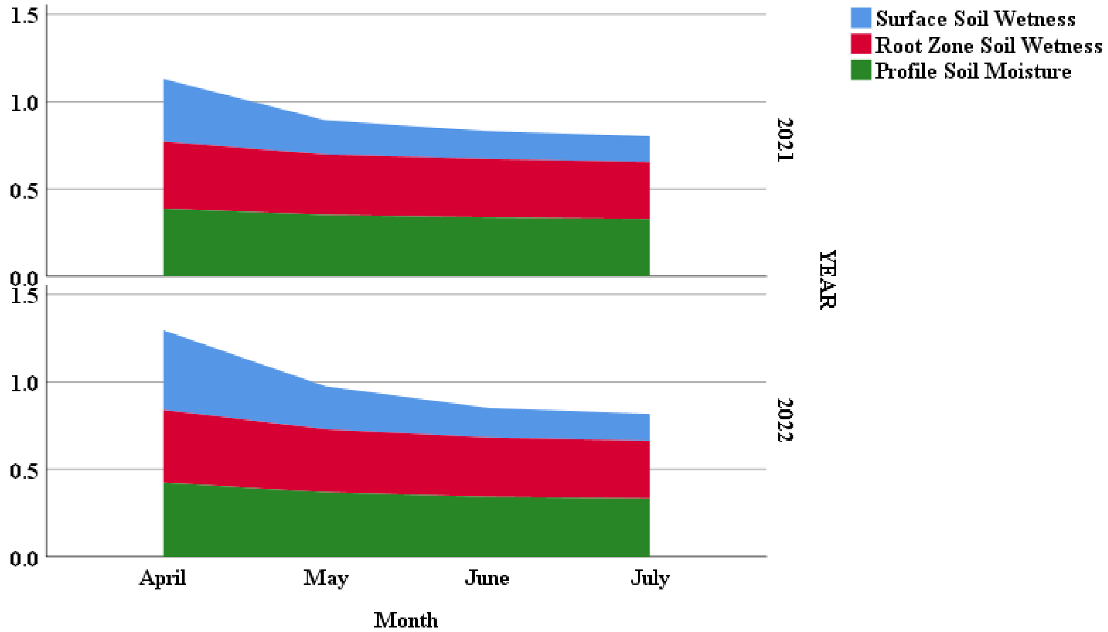


Fig. 2. Surface, root zone soil wetness and profile soil moister (1) of the experimental site during cultivar seasons 2021 and 2022.

Table 2. The chemical composition of poultry manure.

Organic matter, %	Organic carbon	C/N	pH	EC, dS^{-1} m (1:2)	Total N, %	Available Nutrient (mg kg^{-1})		
						N	P	K
43.1	25	12.5	6.7	2.1	2	90	50	200

Table 3: Physical and chemical properties of experimental soil

Seasons	**Particle size distribution (%)**			**Texture class**	**OM (%)**	**EC (dS m^{-1}) (1:5)**	**pH (1:2.5)**	**ESP (%)**	**Available (mg kg^{-1} soil)**		
	Sand	**Silt**	**Clay**						**N**	**P**	**K**
1st	62.7	18	19.3	Sandy loam	0.6	3.85	8.65	18.97	24.1	3.87	110
2nd	60.8	18.2	20	Sandy loam	0.7	3.55	8.6	18.55	25.5	4.00	120

OM = Organic matter **EC = Electrical conductivity**
pH = Hydrogen ion concentration (acidity) **ESP = Exchangeable Sodium Percentage**

3. Results

3.1 Plant Growth and Yield Parameters

The application of different soil amendments had a significant effect (p≤0.01) on plant height, fresh root weight, plant weight, stem diameter, number of leaves per plant, fresh and dry weight of 6 leaves, and leaf area in both seasons Figs. 3, 4, 5, 6, 7 and 8, respectively. The combined application of humic acid, organic matter, and gypsum (HA+OM+GP) resulted in the tallest plants (154 and 218.8 cm) and the highest plant weight (1.10 and 1.13 kg) in both seasons.

The combination of HA+OM+GP also resulted in the highest number of leaves per plant (32 and 33.92), fresh weight of 6 leaves (124.3 and 131.7 g) and dry weight of 6 leaves (29.2 and 30.95 g), and leaf area (2159 and 2245 cm^2) in both seasons. This two-season study evaluated the effects of various soil amendments on okra yield components including pod length, pod weight (fresh and dry) (Table 4) and marketable yield, unmarketable yield, and total yield (Figs. 9, 10 and 11, respectively). The different treatments significantly (p≤0.01) influenced yield attributes like pod length, fresh and dry weights of pods, marketable and unmarketable yield, and total yield over the two seasons. Pod length significantly increased with all amendments compared to control in both seasons, with FA resulting in the most extended pods. Pod fresh weight also increased with amendments versus control, again the highest with FA. Pod dry weight followed similar trends. Marketable yield was lowest in the control and significantly improved by all treatments in both seasons. HA + OM + GP led to the highest marketable yield, followed by FA + OM + GP. The combined application of HA+OM+GP resulted in the most extended pods (4.60 and 4.78 cm), the highest fresh weight of pods

(98.6 and 103.52 g), and maximum marketable yield (10882 and 11210 kg ha^{-1}). Unmarketable yield markedly increased with FA and HA in the second season. Total yield was lowest in control and the highest with HA + OM + GP, increasing by over 90% versus control.

3.2 Nutrient concentration and uptake

The present study evaluated the effects of various soil amendments on the nutritional quality of okra (*Abelmoschus esculentus* L.) leaves and pods, as determined by nitrogen (N), phosphorus (P), and potassium (K) concentrations, across two growing seasons in 2021 and 2022 (Table 5). Results showed that most amendments significantly increased leaf N versus the control, with humic acid + organic matter + gypsum resulting in the highest concentration. Pod N was also improved by several treatments with organic matter, aligning with previous reports on organic fertilizers in okra (Table 5). For P, humic acid and gypsum increased leaf P only in the second season, although no significant impact was observed in pods. This partially agrees with past evidence of increased P uptake with humic acid. The highest leaf and pod P occurred with organic matter + gypsum, consistent with synergistic effects on P availability. All amendments increased leaf and pod K versus control across seasons, particularly humic acid, likely resulting from enhanced K solubility and uptake.

Also, this study evaluated the effects of soil amendments on nitrogen (N), phosphorus (P), and potassium (K) uptake (kg ha^{-1}) in okra pods over two seasons. Treatments included gypsum, organic matter, fulvic acid, and humic acid alone or combined (Table 6). N uptake was significantly increased by all treatments compared to control, with humic acid + organic matter + gypsum resulting in the highest uptake. Similar trends were observed for P uptake, with the largest increase under humic acid + organic matter + gypsum. All amendments significantly improved K uptake versus control, especially humic acid + organic matter + gypsum.

3.3 Soil Properties

This study evaluated the impact of various soil amendments on electrical conductivity (EC), pH, cation exchange capacity (CEC), and exchangeable sodium percentage (ESP) of soil after okra cultivation for two seasons (Table 7). Treatments did not substantially affect EC or pH versus the control across seasons. CEC increased with organic matter, fulvic acid, and humic acid in the second season compared to the first. ESP markedly decreased with gypsum and remained low with humic acid + organic matter + gypsum in both seasons.

3.4 Economic analysis

Application of the solo gypsum (GP) amendment resulted in the highest marketable yield increment of 41%, leading to gross returns of 146720 LE ha^{-1} over control. Although GP had the lowest amendment cost, the total variable costs increased by 6.7% over control, leading to a net return enhancement of 60.9%. Integrated application of humic acid, organic matter, and gypsum gave the highest marketable okra yield across treatments at 11046 kg ha^{-1}, which was almost double that of control. This 112% yield increase under the HA+OM+GP combination resulted in optimum gross returns of 220920 LE ha^{-1}, which was also the maximum among all treatments. Despite having the second highest amendment expenses, net profit under the HA+OM+GP combo was substantially higher by 126.5% over control owing to a disproportionate enhancement in yields and resultant revenues. Contrastingly, solo humic acid (HA) increased net income by only 13% compared to control, while solitary organic matter (OM) treatment registered negligible change versus control. Hence, combined applications were notably superior to individual components, showing a synergistic effect between amendments. HA+OM+GP also gave the highest benefit cost ratio of 3.49, indicating excellent returns on investment.

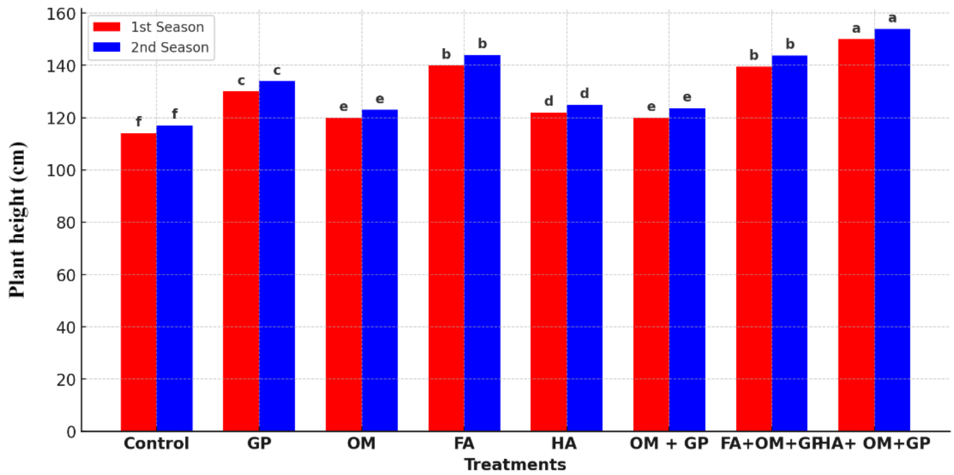


Fig. 3. Effect of different soil amendments on plant height of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

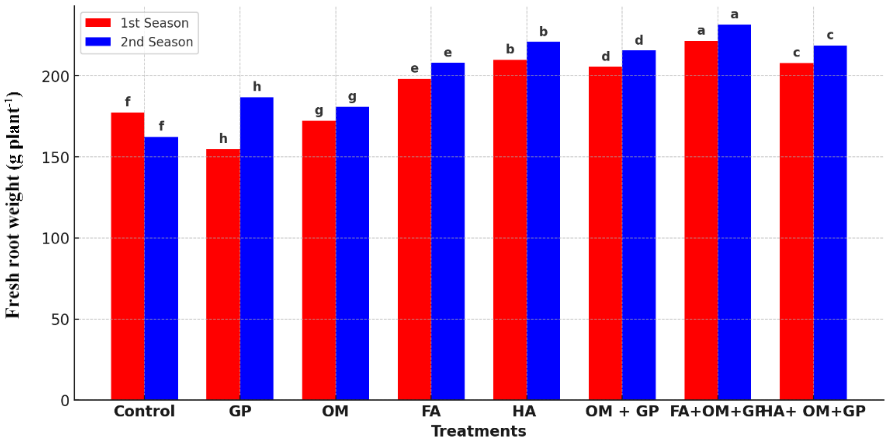


Fig. 4. Effect of different soil amendments on fresh root weight of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

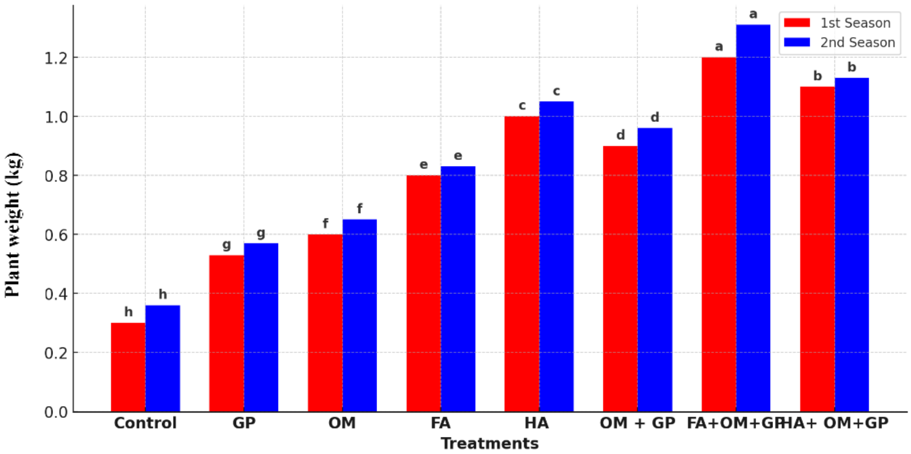


Fig. 5. Effect of different soil amendments on plant weight of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

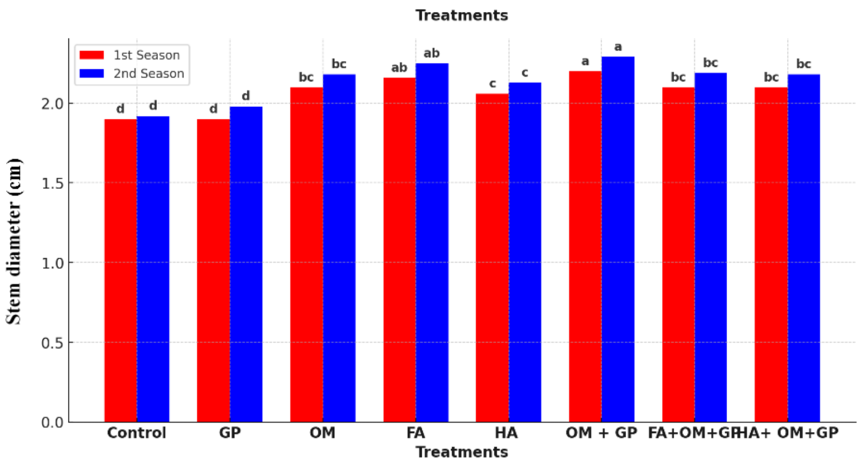


Fig. 6. Effect of different soil amendments on stem diameter of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

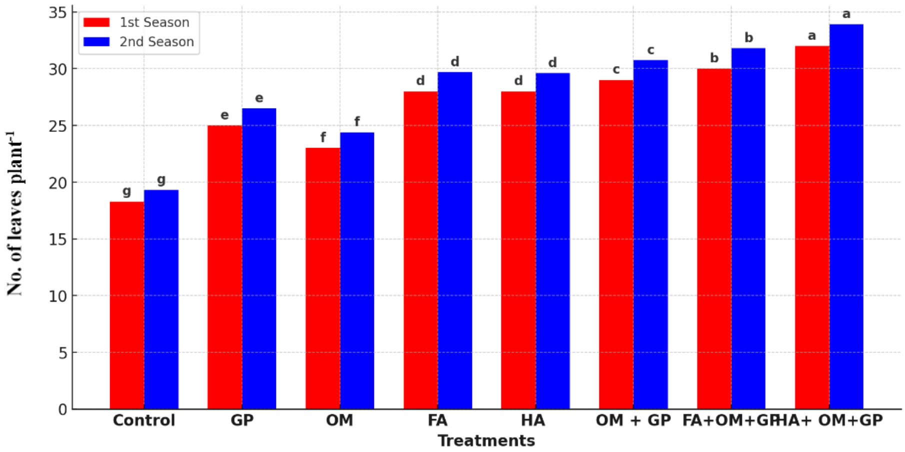


Fig. 7. Effect of different soil amendments on No. of leaves/plant of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

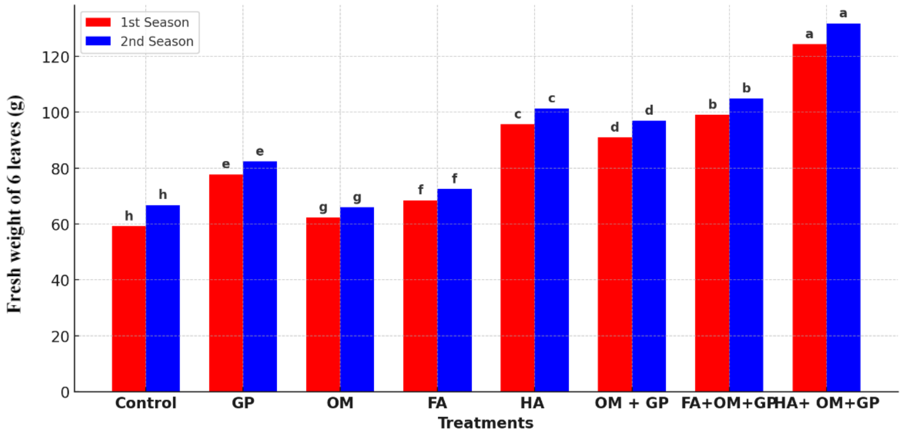


Fig. 8. Effect of different soil amendments on Fresh weight of 6 leaves of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

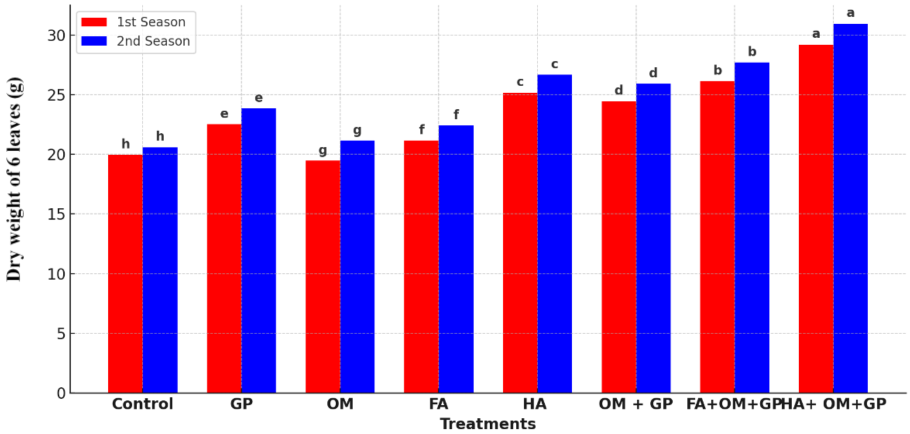


Fig. 9. Effect of different soil amendments on dry weight of 6 leaves of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

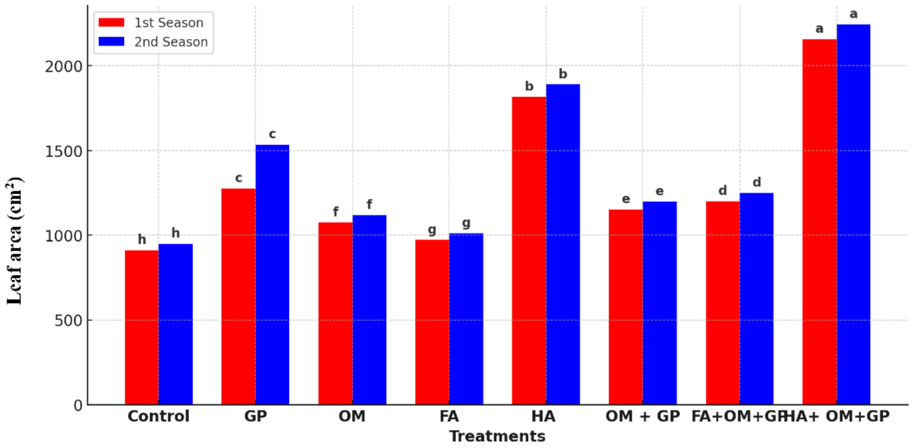


Fig. 10. Effect of different soil amendments on leaf area of okra plant through two cultivar seasons 2021 and 2022.

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Table 4. Effect of different soil amendments on yield parameters of okra plant through two cultivar seasons 2021 and 2022.

Treatments	Pods length (cm)		Fresh weight of 10 pods (g)		Dry weight of 10 pods (g)	
	1st	2nd	1st	2nd	1st	2nd
Control	4.26 fg	4.26 g	65.60 g	68.9g	21.40 f	66.7 h
GP	4.30 f	4.30 f	66.76 f	70.1 f	21.10 g	82.37 e
OM	4.20 g	4.32 fg	74.36 e	78.1 e	23.56 e	66.00 g
FA	5.00 a	5.20 a	99.30 a	104.22 a	24.30 c	72.45 f
HA	4.40 e	4.57 e	95.26 b	100 b	25.16 b	101.3 c
OM + GP	4.50 d	4.68 d	88.93 d	93.4 d	24.30 c	96.9 d
FA+OM+GP	4.70 b	4.88 b	91.26 c	95.86 c	29.20 a	104.9 b
HA+ OM+GP	4.60 c	4.78 c	98.6 a	103.52 a	23.93 d	131.7 a
P value	0.05	0.05	0.01	0.01	0.01	0.01

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

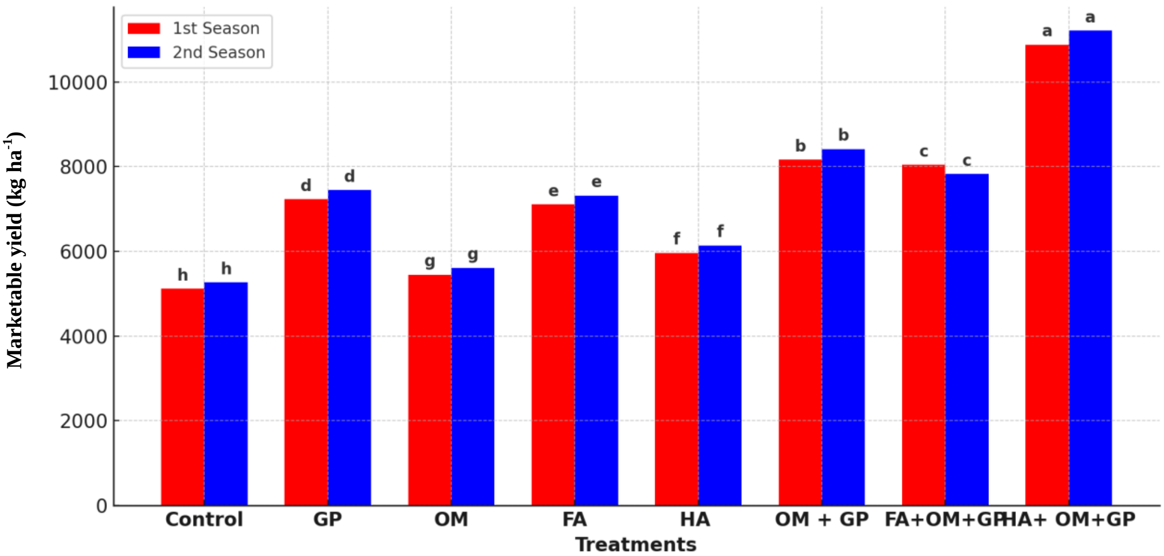
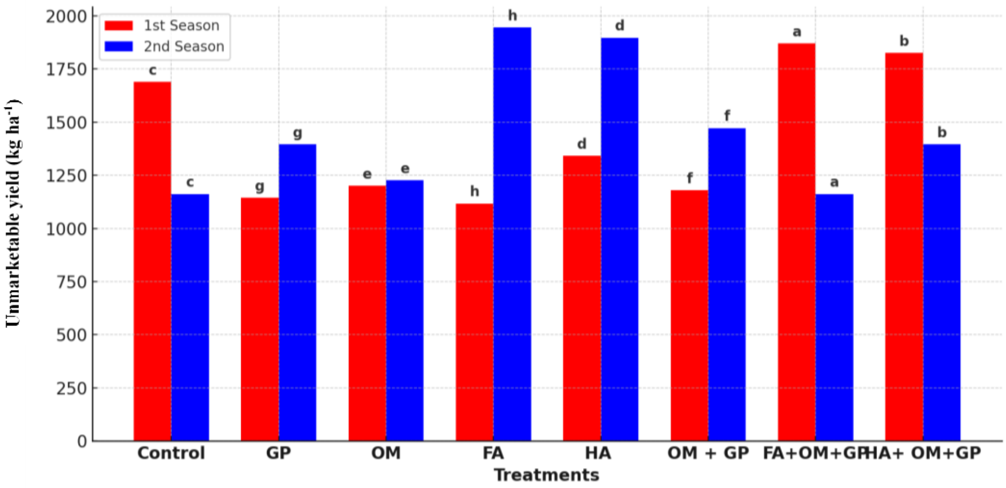


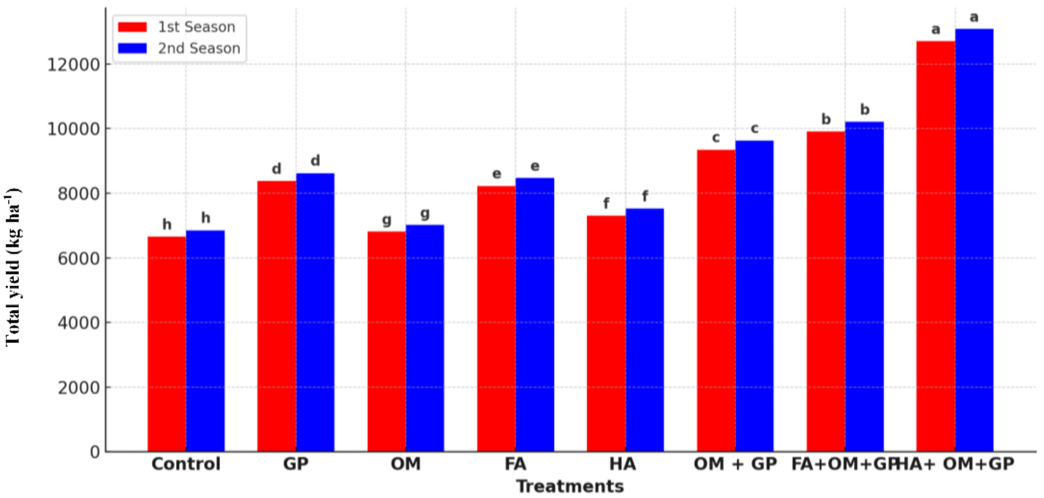
Fig. 11. Effect of different soil amendments on marketable yield of okra plant through two cultivar seasons 2021 and 2022

Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.



GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Fig. 12. Effect of different soil amendments on unmarketable yield of okra plant through two cultivar seasons 2021 and 2022.



GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Fig. 13. Effect of different soil amendments on the total yield of okra plant through two cultivar seasons 2021 and 2022.

Table 5. Effect of different soil amendments on nitrogen, phosphorus, and potassium concentration in okra plant leaves and pods through two cultivar seasons 2021 and 2022.

Treatments	Leaves						Pods					
	N		P		K		N		P		K	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Control	1.93 f	2.11 f	0.46	0.49 f	1.23 e	1.34 e	1.93 d	1.83e	0.66	0.67 c	1.66 f	1.82 f
GP	2.63 b	2.88 b	0.60	0.66 b	1.66 d	1.82 d	2.20 b	2.35 b	0.70	0.77 a	1.86 e	2.03 e
OM	2.20 cd	2.44 cd	0.50	0.56 e	1.23 e	1.35 e	2.50 a	2.59 a	0.60	0.65 d	1.73 f	192 f
FA	2.10 de	2.31 de	0.56	0.61 c	2.56 a	2.81 a	1.96 d	2.02 d	0.60	0.64 d	2.07 d	2.27d
HA	2.30 c	2.50 c	0.60	0.66 b	2.36 b	2.59 b	2.10 c	2.17 c	0.60	0.64d	2.96 a	3.23 a
OM + GP	1.93 f	2.12 f	0.60	0.69 a	1.70 d	1.87 d	2.50 a	2.62 a	0.60	0.66 c	2.76 b	3.04 b
FA+OM+GP	2.00 ef	2.2 ef	0.49	0.47 g	1.80 c	1.99 c	2.07 c	2.16 c	0.50	0.55 e	2.65 c	2.81 c
HA+ OM+GP	2.80 a	3.08 a	0.50	0.58 d	1.80 c	1.99 c	1.96 d	2.05 d	0.70	0.74 b	2.60 c	2.82 c
P value	0.05	0.05	ns	0.01	0.05	0.05	0.05	0.05	ns	0.05	0.05	0.05

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Table 6. Effect of different soil amendments on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) in okra plant pods through two cultivar seasons 2021 and 2022.

Treatments	N-Uptake in pods		P-Uptake in pods		K-Uptake in pods	
	kg ha^{-1}					
	1st	2nd	1st	2nd	1st	2nd
Control	131.3 h	131.0h	44.08 e	45.75 e	113.0 f	117.5 f
GP	187.5 d	195.0 d	61.40 b	63.90 b	154.9 e	161.0 e
OM	164.0 e	170.5 e	41.15 f	42.83 f	116.2 f	121.2 f
FA	143.3 g	149.0 g	50.65 d	52.65 d	169.8 d	176.5 d
HA	151.3 f	157.3 f	37.15 e	46.50 e	212.5 c	222.5 c
OM + GP	233.5 b	242.8 b	59.15 c	61.50 c	257.5 b	267.5 b
FA+OM+GP	203.8 c	211.9 c	51.75 d	53.75 d	252.5 b	262.5 b
HA+ OM+GP	248.5 a	257.5 a	89.00 a	92.50 a	325.0 a	337.5 a
P value	0.01	0.01	0.05	0.05	0.05	0.05

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Table 7. Effect of different soil amendments on soil after Okra cultivars.

Treatments	EC (dS m^{-1}) (1:5)		pH (1:2.5)		CEC (mmolc kg^{-1})		ESP (%)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Control	3.11	3.21	8.45	8.28	28.13	29.26	18.97	18.60
GP	2.88	2.97	8.24	8.08	28.13	29.26	13.62	13.35
OM	3.15	3.25	8.18	8.02	29.69	30.88	12.43	12.19
FA	3.22	3.32	8.40	8.23	31.24	32.49	12.61	12.36
HA	3.80	3.91	8.41	8.24	37.46	38.96	10.13	9.93
OM + GP	4.30	4.43	8.14	7.98	29.69	30.88	12.82	12.57
FA+OM+GP	4.22	4.34	8.37	8.20	31.24	32.49	12.38	12.14
HA+ OM+GP	2.77	2.86	8.40	8.23	39.02	40.58	9.98	9.78

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid and HA= Humic acid.

Table 8. Economic analysis of okra yield response to soil amendments.

Treatment	Pooled Marketable yield (kg ha^{-1})	Gross return (LE ha^{-1})	Amendment unit price (Local commercial price, LE)	Amendment costs (LE ha^{-1})	Total variable cost (LE ha^{-1})	Net return (LE ha^{-1})	Benefit cost Ratio	order
Control	5196	103920	-	-	43150	60770	2.41	6
GP	7336	146720	300	2850	46000	97870	3.19	3
OM	5531	110620	50	4775	47925	57920	2.31	7
FA	7213.5	144270	25	15625	58775	69870	2.45	4
HA	6053.5	121070	20	12500	55650	52920	2.18	8
OM + GP	8292.5	165850		7625	50775	107450	3.27	2
FA + OM + GP	7937	158740		23250	66400	69090	2.39	5
HA + OM + GP	11046	220920		20125	63275	137520	3.49	1

GP= Gypsum, OM= Organic matter as poultry manure, FA= Fulvic acid, HA= Humic acid.

4. Discussion

The table and figures outlining key climatic variables at the experimental site during the okra growing seasons in 2021 and 2022. Several measures are reported over the summer months each year, including precipitation, humidity, wind speeds, and temperatures. The site generally experienced hot, dry conditions with maximum temperatures frequently exceeding 35°C and no rainfall recorded in June or July. These prevailing weather patterns could plausibly influence the outcomes of the soil amendment treatments in multiple ways. High heat and low moisture tend to exacerbate conditions like soil salinity and alkalinity that the added organic matter and gypsum aimed to mitigate. The harsh summer climate also creates physiological stress for okra plants, potentially limiting growth and yields to some degree for all treatments. However, quantifying such effects would require controlled experiments isolating weather variables. The climate table provides useful context about the environmental conditions under which the field study occurred. While it is difficult to directly relate the reported weather factors to specific treatment results, they characterize the overall semi-arid production situation facing okra crops in the region. The trends also suggest that moisture and temperature extremes each year could noticeably alter plant response across amendment regimens. Discussion of growing season climate would benefit future efforts to interpret and apply these findings.

The organic and inorganic amendments caused appreciable improvement in soil properties, creating a more favourable environment for plant growth and yield. The humic substances provide binding sites for plant nutrients, improve soil structure, and increase microbial activity (Nardi et al., 2021; Rashad et al., 2022; Tiwari et al., 2023). As evidenced by our results, the HA+OM+GP treatment led to the maximum increase in plant growth parameters like height and leaf numbers likely due to these positive effects of humic substances on soil fertility and structure. Gypsum application improves soil physical properties like aggregation and porosity, enhancing root development and nutrient acquisition (Bello et al., 2021; Elsherpiny, 2023; Walia & Dick, 2018). The improvements in pod yield and nutrient uptake with gypsum-containing treatments can be attributed to increased root growth and mobility of ions like calcium in the soil solution.

Results demonstrate the potential of soil amendments to improve macronutrient contents in okra, which can enhance nutritional quality for consumers. Organic matter appeared most effective at increasing pod N and P, attributed to slow mineralization and synergies with native soil nutrients (Oyetunji et al., 2022). Our results align with these previous reports showing the highest pod N with organic matter application. Humic acid showed greatest benefits for K, agreeing with previous reports on humic effects on K availability. The higher leaf and pod K concentrations under humic acid align with its known influence on K mobility and acquisition (Farid et al., 2023; Kaya et al., 2018; Saad Mohamed, 2020).

The better yields obtained with HA+OM+GP could be related to enhanced photosynthetic activity and more significant mobilization of nutrients and carbohydrates to the fruiting bodies as a result of humic acid application (Cristofano et al., 2021). The higher nutrient uptake with HA+OM+GP was attributed to greater biomass production and higher nutrient concentrations in plant parts. Integrated nutrient management involving both organic and inorganic sources has been found beneficial for enhancing nutrient uptake and use efficiencies in crop plants (Bargaz et al., 2018).

The decrease in pH with soil amendments could be due to the production of organic acids and release of hydroxyl and humic acids from decomposing organic matter (Kwatkowska-Malina, 2016; Sun et al., 2021). Application of humic substances can increase soil CEC due to their high cation exchange capacities (Han et al., 2023; Ramos et al., 2018). The decrease in ESP with gypsum application is well documented, and is attributed to the displacement of Na^+ ions from exchange sites by Ca^{2+} ions released from gypsum (Hasana et al., 2022; Morsy et al., 2022).

Thus, the integrated application of organic and inorganic amendments resulted in synergistic effects leading to optimal plant growth, yield, and quality of okra under saline soil conditions. The amendments improved the physical, chemical, and biological properties of soil, creating a favourable environment for crop productivity.

Combining organic matter with GP performed better than their individual addition, confirming positive synergistic action between organic and inorganic components as noted before (Kaledhonkar et al., 2019). The economic gains under integrated HA+OM+GP treatment versus solo organic matter input that dominates conventional small farm practice highlights its agronomic and commercial viability for okra grown in salt affected soils. Although amendment costs were understandably greater for HA+OM+GP, this initial investment could be justified by the over two-fold increment in marketable yield and almost three-fold increase in total variable cost translating to substantially higher net profitability. The lower yields and economic returns for individual HA or OM amendments point towards their enhanced effectiveness under integrated approach. Further analysis over multiple seasons can shed light on temporal profitability considering the expected persistent benefits of combined amendments in remediating saline-sodic soils. Policy measures like subsidies on amendment costs could also bolster adoption of integrated management practices among resource-poor farmers.

5.Conclusion

Application of humic acid, organic matter and gypsum was most effective in enhancing growth, yield, quality and nutrient uptake of okra grown in alkaline soil. The amendments caused significant improvement in soil health as evidenced by changes in properties like pH, EC, CEC and ESP. The integrated use of organic and inorganic resources resulted in synergistic effects leading to optimal plant growth and productivity under salinity stress. The use of poultry manure ensured an adequate supply of nutrients besides promoting long-term soil fertility. The study underscores the importance of a holistic approach combining organic and inorganic inputs for sustainable reclamation and productivity of salt-affected soils. The HA+OM+GP combination led to optimal okra productivity under salinity stress. Besides increasing yields and revenues, integrated application improved soil health. Although amendment costs were greater for

HA+OM+GP than individual components, the net profit per hectare after costs was markedly higher than traditional organic amendment practices. With residual benefits expected over time, combined application of humic acid, organic matter and gypsum could be an efficient and economically viable strategy for reclaiming alkaline soils for sustainable okra production.

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