Soil urease, acid and alkaline phosphatase enzyme activities as affected by the integration of Organic and inorganic fertilizers under sweet potato cultivation

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ABSTRACT: Declining soil fertility remains one of the major challenges limiting sustainable sweet potato (*Ipomoea batatas* L.) production, especially in tropical regions. Fertilizer application, both through the soil and as foliar sprays, offers opportunities not only to improve crop yield but also to sustain soil biological processes. The field experiment was conducted at the Experimental Station of the Department of Crop, Soil and Pest Management, Teaching and Research Farm, Federal University of Technology, Akure, Ondo state Nigeria to establish the effects of soil and folia applied fertilizers on soil urease, acid and alkaline phosphatase under potato cultivation. The Experimental design was a Randomized Complete Block Design with nine (9) treatments which include, soil applied poultry manure and NPK, folia applied supergro and urea, their combinations and control. Data were collected on vegetative growth, yield components, soil enzyme activities (urease, acid phosphatase, alkaline phosphatase), and soil chemical properties. The results showed that poultry manure and NPK significantly improved vine length and leaf number, while foliar-applied urea and SuperGro enhanced tuber yield. Enzyme activities were generally higher under organic and integrated treatments compared to sole inorganic applications, indicating improved microbial activity and nutrient cycling. Soil properties such as organic carbon, total nitrogen, and available phosphorus were also enhanced under poultry manure and combined applications. The findings highlight that integrating soil and foliar fertilizers provides a more sustainable approach to sweet potato production than relying solely on inorganic inputs. Integrated nutrient management not only boosts crop yield but also enhances soil fertility and enzymatic activity, offering farmers a practical and environmentally sound strategy for long-term productivity.

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Introduction

Sweet potato (Ipomoea batatas L.) is an important root and tuber crop widely cultivated in tropical and subtropical regions for its high carbohydrate, vitamins, and mineral contents (Woolfe, 1992; Lebot, 2009). In Nigeria, it serves as a food security crop due to its adaptability to diverse soil conditions, short maturity period, and relatively low input requirements (Odebode *et al*., 2016). However, soil nutrient depletion and declining soil biological quality have been identified as major constraints to sustainable sweet potato production (Okon et al., 2019). Hence, appropriate nutrient management strategies are essential to enhance soil fertility, enzymatic activities, and crop productivity.

Soil enzymes such as urease, acid phosphatase, and alkaline phosphatase are critical indicators of soil biological activity and fertility (Dick et al., 1996; Nannipieri et al., 2012). These enzymes mediate key biochemical transformations that release essential plant nutrients from organic and inorganic sources. Urease catalyzes the hydrolysis of urea into ammonium and carbon dioxide, playing a central role in nitrogen mineralization (Kandeler and Gerber, 1988). Similarly, acid and alkaline phosphatases catalyze the hydrolysis of organic phosphorus compounds to orthophosphate, facilitating phosphorus availability to plants (Tabatabai and Bremner, 1969). Therefore, changes in their activities reflect soil nutrient status and microbial functional dynamics under different management practices (Burns et al., 2013).

The application of fertilizers (both soil- and foliar-based) affects the activity of these enzymes through modifications in nutrient availability, soil pH, and microbial biomass (Ajwa et al., 1999; Das and Varma, 2011). Inorganic fertilizers such as NPK (20:10:10) and urea are known to supply readily available nutrients that enhance plant growth; however, excessive use can suppress soil enzyme activities by lowering soil pH and altering microbial populations (Guo et al., 2010; Geisseler and Scow, 2014). Conversely, organic amendments like poultry manure provide a slow and sustained release of nutrients and organic matter, stimulating microbial proliferation and enzyme synthesis (Ndubuisi-Nnaji et al., 2015; Chukwu et al., 2021). Organic inputs improve soil structure, cation exchange capacity, and enzymatic functioning compared to chemical fertilizers alone.

Foliar fertilizers, such as liquid organic formulations and urea sprays, deliver nutrients directly through leaf surfaces, enhancing nutrient uptake efficiency and crop productivity, especially in nutrient-deficient or stress conditions (Fageria et al., 2009). When used in combination with soil-applied fertilizers, foliar nutrition can balance soil nutrient dynamics and stimulate microbial activities indirectly through improved root exudation and rhizosphere interactions (Fernández and Eichert, 2009; Anjana and Yadav, 2020). The integrated use of organic and inorganic fertilizer has been shown to synergistically enhance soil enzyme activities, microbial functioning, and nutrient cycling (Mahanta et al., 2018; Adekiya et al., 2019).

Despite extensive studies on fertilizer impacts on soil fertility and crop yield, limited attention has been given to how combined soil and foliar fertilization strategies influence soil enzyme activities under sweet potato cultivation, particularly in tropical soils. Understanding these interactions is essential for developing sustainable nutrient management practices that optimize both crop productivity and soil biological health.

Therefore, this study evaluates the effects of soil and foliar applied fertilizers on soil urease, acid, and alkaline phosphatase enzyme activities, alongside changes in soil chemical properties and sweet potato growth parameters.

Material and Methods

The field experiment was conducted at the Experiment Station of the Department of Crop, Soil and Pest Management, Teaching and Research Farm, Federal University of Technology, Akure between March and August. The farm is located in the rain forest vegetation zone (7°16′N, 5°12′E) of Nigeria. Akure is characterized by a semi-arid to humid climate with a mean annual temperature of 26^{0}C, relative humidity of about 15% and average annual precipitation of about 1400 mm, most of which occurs from May to September. The topography of the area is flat and gradient is less than 3%. The soil at the site is classified as Typic Paleustalf Alfisol, with clay content of 15–28% and sand content of 26–32% (Soil Survey Staff 2014).

All solvents and chemicals used in this study were of analytical grade and obtained from Pascal Chemical Company Ltd., Akure, Nigeria. The soil and foliar-applied fertilizers included SuperGro (SG) and Urea, respectively.

The field experiment was conducted on a site measuring 17 m × 23 m, which was manually cleared of weeds and crop residues using a cutlass and ridges were constructed with a hoe. Each ridge measured 5 m in length and was spaced 1 m apart. A 1 m alley separated adjacent blocks. The experiment was arranged in a Randomized Complete Block Design (RCBD) comprising nine treatments, each replicated three times, giving a total of 27 plots. Each treatment occupied two ridges per block.

The planting material consisted of sweet potato (*Ipomoea batatas* L.) vine cuttings, each measuring approximately 5 cm in length with five nodes. The vines were planted on the ridges with leaves facing upward to ensure proper establishment. Six vines were planted per ridge, resulting in 12 vines per plot and a total of 324 vines across the entire field.

The experimental treatments and application rates were as follows:

1. Poultry manure (PM) at 5 t ha^{-1}
2. NPK (20:10:10) at 300 kg ha^{-1}
3. SuperGro (SG) at 3 ml per 3 L of water
4. Urea (foliar spray) at 40 ml per 3 L of water
5. PM at 2.5 t ha^{-1} + SG at 1.5 ml per 3 L of water
6. PM at 2.5 t ha^{-1} + Urea at 20 ml per 3 L of water
7. NPK at 150 kg ha^{-1} + SG at 1.5 ml per 3 L of water
8. NPK at 150 kg ha^{-1} + Urea at 20 ml per 3 L of water
9. Control (no input)

Poultry manure was applied one week before planting, NPK fertilizer was applied two weeks after planting, while foliar fertilizers (SuperGro and Urea) were applied four weeks after planting and subsequently at two-week intervals until crop maturity.

All plots received uniform agronomic practices such as weeding, pest control, and irrigation where necessary to minimize external variability and ensure the reliability of treatment effects.

Growth and Yield Collection

Five plants were randomly selected and tagged in each plot for data collection and consistently sampled all through the period of the experiment. Plant growth data were collected at 5, 7, 9 and 16 WAP while the yield attributing parameters were collected at harvest (16 WAP). The length of the main vine was measured from the base at the soil surface to the apex using a measuring tape and the average was recorded. All fully expanded leaves on the main vine were counted and the average recorded. Yield data was collected at harvest (about 16 WAP) and the components measured were numbers of marketable tubers per plant, number of non-marketable tubers per plant, average tuber weight (kg), and tuber length and diameter (cm).

Soil Sampling

Soil samples were collected from each plot at 12 weeks after planting and taken from the top 0-15cm of the soil layer using a soil auger and thoroughly mixed to obtain a composite sample for each plot. Samples were air-dried, then sieved through a (<2mm) sieve to remove plant materials, soil micro fauna and stones and the samples were stored in a clean, airtight container to avoid contamination and the samples were kept at 60% WHC until urease enzyme determination.

Assay for soil enzyme activities

The activities of urease, acid and alkaline phosphatases were all assayed using the described procedures of Tabatabai [68]. For urease enzyme activity determination, five grams of soil (< 2 mm) was exposed to 9 mL of 0.1 M trishydroxymethylaminomethane (THAM) buffer and 1 mL of 0.5 M substrate urea solution in a 50 mL volumetric flask. The flask was stoppered, shaken vigorously for 1 min and placed in an incubator at 37 °C. After 2 h, the stopper was removed and approximately 35 mL of $KCl\text{-}Ag_2SO_4$ solution was added (the content was then made to 50 mL by adding $KCl\text{-}Ag_2SO_4$ solution), swirled again for a few seconds, and allowed to stand for about 5 min to cool. The ammonium nitrate (NH4 +-N) concentrations in the resulting soil suspensions were determined by steam distillation with 0.2 g of MgO for 4 min. The liberated NH4 +-N was thereafter trapped in a conical flask containing 10 mL of 2% boric acid to which mixed (bromocresol green and methyl red) indicator solution have been added. The distillate collected was finally titrated against 0.005 M H2SO4 solution. Note that 1 ml of H2SO4 (0.005 M) is equivalent to 70 mg NH4 +-N. The results for the controls were corrected and final results obtained were in the form; mg NH4 +-N g−1dwt 2 h−1. For Acid and alkaline phosphatase activities, 4 mL of modified universal buffer (MUB, pH 6.5 and 11.0 for acid and alkaline phosphatases, respectively) and mL of 0.05 M ρ-nitrophenol-phosphatedisodium (PNPP) substrate solution made in the same buffer were all added to 1 g of sieved soil < 2 mm in a test tube and centrifuged for a few minutes to mix the contents, stoppered and placed in an incubator at 37 °C for 1 h. After 1 h, the stopper was removed and reaction was stopped with 1 mL of 0.5 M $CaCl_2$ and 4 mL of 0.5 M NaOH solution. The tube was centrifuged again for a few minutes and the resulting soil suspension was filtered through a Whatman filter paper no. 2v.

The yellow colour intensity of the filtrate was read using 721G-Visible Spectrophotometer at a wavelength of 400 nm

Soil chemical analysis

Composite soil samples collected before treatment application and from individual treatment plot at potato harvest was air-dried, ground and sieved using 2mm sieve mesh. They were chemically analysed as described by Tel (1984). Organic matter was determined by wet oxidation method through chronic acid digestion. Nitrogen was determined by microkjeldahl approach, P was extracted by Bray-P1 solution and determined using ammonium acetate, K was determined using flame photometer, and Ca and Mg by EDTA titration method. Soil pH in ratio 1:2 water suspension was determined using a glass electrode.

Data Analysis

Statistical analysis of data collected was conducted using the one-way analysis of variance (ANOVA) procedure in MINITAB Statistical Software [42] to test for the treatment effects on each of the measured parameters. Significant differences among the treatment means were compared using Tukey test at $p \leq 0.05$. Also, means were estimated to construct graphs using Microsoft excel 2007.

RESULTS

Effects of Treatments on the Vine Length and number of leaves of Sweet Potato

The effects of soil and folia applied fertilizers on vine length of sweet potato at different growth stages are shown in Table 1. At the early stage (5 WAP), plot treated with NPK and foliar applied supergro produced significantly higher leaf numbers than treatment under poultry manure and the control. During the mid-growth stages (7–9 WAP), the effects became more pronounced, as NPK, foliar spray, and integrated treatments such as poultry manure with urea or supergro gave significantly greater leaf numbers than sole poultry manure. At the late stage (16 WAP), NPK and integrated treatments still maintained higher leaf numbers than the control, which consistently recorded the lowest values throughout. Table 2 presents the effects of the fertilizer treatments on the number of leaves of sweet potato at 5, 7, 9, and 16 weeks after planting. At the early stage (5 WAP), NPK treatment produced significantly longer vines than the control, while foliar applied supergro also showed an advantage over poultry manure treatment. By the mid-growth stages (7–9 WAP), NPK and integrated treatments (poultry manure with urea or supergro) maintained significantly greater vine elongation than sole poultry manure and the control. At the late stage (16 WAP), these treatments continued to sustain longer vines, while poultry manure alone remained the least effective among fertilizer applications, though still superior to the control.

Table 1. Effects of treatments on the vine length of sweet potato

	Weeks after planting			
Treatments	5	7	9	16
PM	59.8c	106.8cd	200.2a	247.4bc
NPK	83.5b	146.7ab	206.3a	259.0ab
SG	110.2a	169.9a	206.4a	285.3a
UREA	41.8c	95.4d	182.7ab	222.0cde
PM + SG	93.5ab	106.3cd	210.2a	227.5cde
PM + UREA	102.3ab	152.3ab	210.7a	212.8de
NPK + SG	90.6ab	130.0bc	172.2ab	235.7bcd
NPK + UREA	53.9c	797.0d	141.4ab	241.4bcd
CONTROL	101.2ab	81.7d	104.2b	204.4e

Means followed by the same letter in the same column are not significantly different from each other by Tukey's HSD at 5% level of probability.

Table 2. Effects of treatments on the number of leaves of sweet potato

	Weeks after planting			
Treatments	5	7	9	16
PM	69.2bc	186.3bcd	276.6cd	306.6b
NPK	170.3a	299.1ab	490.0ab	442.4b
SG	86.8bc	306.6a	601.9a	395.0b
UREA	76.8bc	137.3cd	303.5cd	401.0b
PM + SG	83.3bc	187.5bcd	338.6cd	374.3b
PM + UREA	157.0a	251.6abc	333.5cd	690.1a
NPK + SG	107.0b	208.8abcd	403.2bc	379.6b
NPK + UREA	61.8c	266.0abc	242.9d	333.0b
CONTROL	188.4a	96.0d	242.4d	305.3b

Means followed by the same letter in the same column are not significantly different from each other by Tukey's HSD at 5% level of probability.

Effects of Treatments on Yield of Sweet Potato

Results of the effects of soil and foliar applied fertilizers on the yield of sweet potato are presented in table 3. Foliar applied urea treatment resulted in the heaviest and longest tubers, while plot treated with NPK significantly increased tuber diameter and gave the highest yield per hectare. Foliar applied Supergro treatment produced the greatest number of marketable tubers and reduced the proportion of unmarketable ones. The combined treatments performed better than the control treatment, although their effects were not always significantly different from the sole fertilizer applications. Across all parameters measured, the control consistently performed poorly, producing the least yield and the highest number of non-marketable tubers.

Table 3: Effects of soil and folia applied fertilizers on the yield of sweet potato

Treatments	Average tuber Weight.	Tuber Length	Tuber Diameter	Marketable	Non - Marketable	Yield (t/ha)
PM	1.38abc	15.19bc	18.06ab	12.33a	4.00b	8.21ab
NPK	1.37abc	14.39bcd	17.88ab	12.00a	11.66a	11.93a
SG	1.42abc	15.48bc	18.60a	15.00a	3.00b	11.76ab
UREA	1.80a	18.96a	18.07ab	14.66a	2.33b	9.38ab
PM + SG	1.53abc	17.68ab	18.76a	14.67a	4.00b	8.60ab
PM + UREA	1.14c	14.95bc	17.20ab	11.66a	3.00b	8.99ab
NPK + SG	1.17bc	14.07cd	15.82ab	11.95a	11.00a	9.99ab
NPK+UREA	1.66ab	13.60cd	16.14ab	11.68a	10.66a	10.67ab
CONTROL	1.09c	11.46d	15.02b	11.00a	12.00a	7.74b

Means followed by the same letter in the same column are not significantly different from each other by Tukey's HSD at 5% level of probability.

Soil Enzyme Activities

The influence of fertilizer treatments on soil urease, acid, and alkaline phosphatase activities is presented in Table 4. Urease activity was generally uniform across treatments, with only slight differences observed. For alkaline phosphatase, higher activity was associated with the control treatment and NPK treatments, while markedly lower values occurred when NPK was combined with urea or SuperGro. In the case of acid phosphatase, plot treated with NPK and its combination with urea gave the highest activities, whereas the lowest was observed under plot treated with PM combined with urea.

Table 4: Effects of soil and folia applied fertilizers on soil urease, acid and alkaline phosphatase

Treatments	Urease (mg $NH_4^{-N}g^{-1}$soil $2h^{-1}$)	Alkaline phosphatase	Acid phosphatase
PM	0.05b	14.6bc	36.2bcd
NPK	0.10a	26.1a	67.8a
SG	0.05b	12.1bc	35.4bcd
UREA	0.05b	3.2d	45.3bc
PM + SG	0.10a	19.0ab	30.5cde
PM + UREA	0.05b	14.0bc	16.6e
NPK + SG	0.10a	7.8cd	22.5de
NPK + UREA	0.10a	6.9cd	65.3a
CONTROL	0.10a	27.0a	47.8b

Means followed by the same letter in the same column are not significantly different from each other by Tukey's HSD at 5% level of probability.

Effects of Treatments on Soil chemical Properties

The pre-treatment soil chemical status of the experimental site is presented in Table 5a. The experimental soil was slightly acidic and low in organic carbon, total nitrogen, and potassium, with only moderate phosphorus content. Among the exchangeable bases, calcium dominated, followed by magnesium and sodium. These values reflect a generally low fertility status, suggesting the need for nutrient amendment to sustain crop growth. Table 5b presents the effects of soil and foliar fertilizers on soil chemical properties after sweet potato cultivation. Poultry manure and its combinations improved organic matter, phosphorus, and potassium levels, which were significantly higher than under mineral fertilizer and the control. Urea-based applications had a marked effect on total nitrogen, while poultry manure treatment also gave significantly greater nitrogen than the control treatment. Plot treated with NPK improved nitrogen status but did not significantly enhance other soil properties. Overall, each fertilizer treatment altered the soil chemical composition differently, reflecting the type of nutrients supplied.

Table 5: Initial soil chemical analysis of the experimental sites

Soil properties	Values
pH (1:2 H_2O)	5.6
Organic Carbon (%)	0.25
Total N (%)	0.06
Available P (mg kg^{-1})	3.42
Available K (cmol kg^{-1})	0.28
Sodium (cmol/kg^{-1})	0.46
Mg (cmol kg^{-1})	0.9
Ca (cmol kg^{-1})	1.5

Table 5b: Effects of soil and folia applied fertilizers on soil chemical properties

Treatments	pH (H_20)	OC (%)	N (%)	P (mgkg^{-1})	K (cmol kg^{-1})	Na (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
PM	5.42a	0.10c	0.08de	3.34d	0.17bc	0.27ab	1.7cd	0.8d
NPK	5.44a	0.25c	0.04f	14.47a	0.18b	0.25bc	1.4d	0.7d
SG	4.93a	0.29bc	0.12c	1.09e	0.14c	0.20cd	1.8cd	0.7d
UREA	5.71a	0.42bc	0.08de	0.54e	0.22a	0.32a	1.5d	0.8d
PM+SG	5.90a	1.05a	0.20a	3.27d	0.15bc	0.22bcd	5.6a	2.4a
PM+UREA	5.40a	0.29bc	0.10cd	5.60c	0.14c	0.19d	2.22	1.1c
NPK+SG	5.56a	0.19c	0.06ef	10.66b	0.17bc	0.26b	1.4d	0.7d
NPK+UREA	5.31a	0.38bc	0.10cd	1.63de	0.18b	0.23bcd	3.2b	1.6b
CONTROL	5.21a	0.59b	0.16b	1.29de	0.16bc	0.22bcd	2.9b	1.4b

Means followed by the same letter in the same column are not significantly different from each other by Tukey's HSD at 5% level of probability.

DISCUSSION

The study revealed that vegetative growth was most enhanced by integrated approaches: SuperGro (foliar fertilizer) produced the longest vine length, while the combination of poultry manure and urea produced the highest number of leaves. This indicated that the balanced and gradual nutrient release from organic and integrated sources is superior to the sole application of inorganic fertilizers, which often resulted in the least growth values (Adeyeye *et al.*, 2016; Nyarko *et al.*, 2022; Agbede and Oyewumi, 2022; Iroegbu *et al.*, 2022; Law-Ogbomo *et al.*, 2018). Similarly, the highest tuber yields were obtained where poultry manure was combined with either urea or SuperGro, and where NPK was combined with foliar fertilizer, confirming that integrated fertilization ensures immediate nutrient availability while sustaining soil fertility (Vanlauwe *et al.*, 2010; Chivenge *et al.*, 2011; Ayeni *et al.*, 2012; Agbede, 2010; Eze and Orkwor, 2010; Ezui *et al.*, 2016; Ndung'u *et al.*, 2012). While sole inorganic applications of NPK and urea did enhance yields, they performed less effectively than integrated treatments, supporting observations that sole inorganic fertilizers quickly supply nutrients but do not sustain soil fertility, and continuous NPK use may reduce yield over time (Fageria, 2009; Geisseler and Scow, 2014; Makinde *et al.*, 2011). The sole use of foliar fertilizer (SuperGro) provided only moderate improvement, as it cannot fully meet the needs of heavy-feeding crops like sweet potato (Fernández and Eichert, 2009; Sharma *et al.*, 2011).

The study also examined soil biological activity, noting that urease activity was generally uniform, suggesting limited short-term effects from nutrient additions (Klose and Tabatabai, 2000; García-Ruíz *et al.*, 2008; Geisseler and Scow, 2014; Nannipieri et al., 2012). Conversely, alkaline phosphatase activity was highest in the control and NPK treatments but suppressed in combined treatments, suggesting feedback inhibition where high available phosphorus reduces the microbial need to secrete the enzyme (Olander and Vitousek, 2000; Cui *et al.*, 2018; Nannipieri *et al.*, 2012; Turner et al., 2013; Rocabruna *et al.*, 2024). Acid phosphatase activity showed a contrasting trend, peaking under NPK and NPK + urea, suggesting that mineral fertilizers stimulated microbial and root demand for phosphorus mobilization, while the low values under PM + urea may be linked to temporary changes in soil pH or slower mineralization dynamics (Chivenge *et al.*, 2011; Nannipieri *et al.*, 2012; Margalef *et a*l., 2017; He et al., 2021; Cui et al., 2020). Although the combinations tested did not universally enhance enzyme activity, the principles of INM are still supported for maintaining soil health in the long-term by increasing soil organic matter and microbial biomass (Allison and Vitousek, 2005; Chivenge *et al.*, 2011; Faissal *et al.*, 2017; Siebielec *et al.*, 2021; Solangi *et al.*, 2024).

Crucially, the long-term benefits of organic amendments were evident in post-harvest soil analysis, where treatments incorporating poultry manure significantly improved soil fertility. Poultry manure combined with SuperGro increased soil pH from a moderately acidic 5.44 to 5.90 and increased organic carbon and total nitrogen contents compared to control and inorganic treatments (Nwite, 2016; Rahman *et al.*, 2020). Furthermore, while NPK combined with SuperGro resulted in the highest available phosphorus, exchangeable bases like calcium and magnesium were more pronounced in organic treatments, highlighting their ability to enhance soil cation exchange capacity and overall nutrient balance (Law-Ogbomo *et al.*, 2018; Li *et al.*, 2021). The overall findings confirm that combining poultry manure, SuperGro, and inorganic fertilizers offers a viable and sustainable strategy for smallholder farmers, enhancing both crop performance and long-term soil sustainability (Chivenge *et al*., 2011; He *et al*., 2021; Nyarko *et al*., 2022; Iroegbu *et al*., 2022; Zhang *et al*., 2022).

CONCLUSION

The study concludes that integrated nutrient management (INM), combining soil-applied (NPK, poultry manure) and foliar-applied (urea, SuperGro) fertilizers is essential for sustainable sweet potato production. This integrated approach significantly outperformed sole applications, yielding the best results for vine growth, leaf production, yield, and soil enzyme activity (urease, acid phosphatase, and alkaline phosphatase). INM is the key to stimulating nutrient cycling and ensuring long-term soil health.

RECOMMENDATION

The study strongly recommends adopting integrated nutrient management (INM), combining soil-applied NPK/poultry manure with foliar-applied urea/SuperGro, as it provided the best overall performance for sweet potato. Farmers should prioritize poultry manure for long-term soil health, use NPK/urea moderately to prevent degradation, and apply foliar inputs at the right time to boost yield. Further research is necessary to confirm these INM results across different regions.

References

Acosta-Martínez, V., Tabatabai, M. A., & Somasundaram, J. (2007). Enzyme activities as affected by management practices. *Soil Science Society of America Journal*, *71*(3), 530–538.

Adekiya, A. O., Agbede, T. M., & Ojeniyi, S. O. (2019). Integrated use of organic and inorganic fertilizers: Effect on soil properties, enzyme activity, and yield of maize. *International Journal of Recycling of Organic Waste in Agriculture*, *8*(1), 123–133.

Adeyeye, S. A. O., Oladapo, O. O., & Fagbola, O. (2016). Growth response of sweet potato to organic and inorganic fertilizers in southwestern Nigeria. *African Journal of Root and Tuber Crops*, *13*(1), 25–33.

Agbede, T. M. (2010). Organic manure use and sweet potato yield in Nigeria. *International Journal of Agriculture and Biology*, *12*(3), 439–444.

Agbede, T. M., & Oyewumi, A. B. (2022). Effects of poultry manure and NPK fertilizer on soil chemical properties and root yield of sweet potato. *Communications in Soil Science and Plant Analysis*, *53*(16), 2095–2110.

Ajwa, H. A., Dell, C. J., & Rice, C. W. (1999). Changes in enzyme activities and microbial biomass of tallgrass prairie soil as related to burning and nitrogen fertilization. *Soil Biology and Biochemistry*, *31*(5), 769–777.

Allison, S. D., & Vitousek, P. M. (2005). Clonal heterogeneity of soil microbial communities and the effect of phosphorus availability on nitrogen-cycling rates. *Ecology*, *86*(12), 3290–3300.

Anjana, R., & Yadav, R. L. (2020). Foliar nutrition for improved crop productivity and quality: A review. *Journal of Plant Nutrition*, *43*(18), 2743–2763.

Ayeni, L. S., Adetunji, M. T., Ojeniyi, S. O., & Adeyemo, A. J. (2012). Effect of poultry manure and NPK fertilizer on soil and plant nutrient content and growth and yield of *Amaranthus cruentus*. *Journal of Soil Science and Environmental Management*, *3*(6), 110–114.

Burns, R. G., DeForest, J. L., Marxsen, J., Sinsabaugh, R. L., Stromberger, M. E., Wallenstein, M. D., Weintraub, M. N., & Zoppini, A. (2013). Soil enzymes in a changing environment: Current knowledge and future directions. *Soil Biology and Biochemistry*, *58*, 216–234.

Chivenge, P., Vanlauwe, B., Six, J., & Huising, J. (2011). Long-term impact of integrated soil fertility management on organic matter and phosphorus fractions in a savanna soil. *Soil Science Society of America Journal*, *75*(5), 1801–1809.

Chukwu, C., Ezeaku, P. I., & Uba, P. O. (2021). Poultry manure as a sustainable amendment for improving soil biological quality and maize productivity. *Nigerian Journal of Soil and Environmental Research*, *19*(1), 45–52.

Cui, G., Liu, F., Lin, Z., Wu, Q., & Li, C. (2018). Responses of soil enzyme activities and microbial community structure to different fertilization regimes in a long-term experiment. *Applied Soil Ecology*, *125*, 116–123.

Cui, Y., Yan, Z., Gong, Y., & Chen, J. (2020). Effects of straw return on soil microbial community and enzyme activities: A meta-analysis. *Soil and Tillage Research*, *196*, 104473.

Das, S. K., & Varma, A. (2011). Role of enzymes in maintaining soil health. In S. K. Das & A. Varma (Eds.), *Soil Enzymology* (pp. 25–42). Springer, Berlin, Heidelberg.

Dick, R. P., Breakwell, D. P., & Turco, R. F. (1996). Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. In *Methods for Assessing Soil Quality* (pp. 247–272). SSSA Special Publication No. 49.

Eze, P. C., & Orkwor, G. C. (2010). Effects of poultry manure on the yield and yield components of sweet potato (*Ipomoea batatas* (L.) Lam) in Nsukka, Nigeria. *Journal of Crop Science and Biotechnology*, *13*(3), 169–173.

Ezui, G., Franke, A. C., Vanlauwe, B., & Smaling, E. M. A. (2016). Response of cassava to fertilizer application in relation to soil fertility status in Nigeria. *Field Crops Research*, *188*, 1–9.

Fageria, N. K., Filho, M. P. B., Moreira, A., & Guimarães, C. M. (2009). Foliar fertilization of crop plants. *Journal of Plant Nutrition*, *32*(6), 1044–1064.

Faissal, E. R. N., Aissa, M. A., & Raddad, M. (2017). Phosphorus availability and enzyme activities in soil under olive trees after application of phosphate fertilizer and organic amendment. *Journal of Soil Science and Plant Nutrition*, *17*(1), 193–204.

Fernández, V., & Eichert, T. (2009). Uptake of hydrophilic solutes through plant leaves: Current state of knowledge and perspectives of foliar fertilization. *Critical Reviews in Plant Sciences*, *28*(1–2), 36–68.

García-Ruíz, R., Cantú-Silva, I., López-Bello, J., & Trejo, C. (2008). Effects of tillage and fertilization on soil enzymatic activities in a tropical dry forest of Mexico. *Applied Soil Ecology*, *39*(3), 296–303.

Geisseler, D., & Scow, K. M. (2014). Long-term effects of mineral fertilizers on soil microorganisms – A review. *Soil Biology and Biochemistry*, *75*, 54–63.

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J. L., Han, W. X., Zhang, W. F., Wang, D. Y., Zhan, Q. C., Jiang, R. F., Wu, L., Fan, M. S., & Zhang, F. S. (2010). Significant acidification in major Chinese croplands. *Science*, *327*(5968), 1008–1010.

He, M., Sun, M., Zhang, B., Wang, Y., & Li, Y. (2021). Effects of different fertilization treatments on soil enzyme activities and microbial community structure. *Applied Soil Ecology*, *161*, 103856.

Iroegbu, O. O., Nwite, J. C., & Odo, E. A. (2022). Effects of integrated poultry manure and NPK fertilizer on soil fertility and yield of sweet potato. *Journal of Experimental Agriculture International*, *44*(9), 83–94.

Kandeler, E., & Gerber, H. (1988). Short-term assay of soil urease activity using colorimetric determination of ammonium. *Biology and Fertility of Soils*, *6*(1), 68–72.

Klose, S., & Tabatabai, M. A. (2000). Urease activity in soils as affected by long-term nitrogen fertilization. *Soil Biology and Biochemistry*, *32*(10), 1545–1549.

Law-Ogbomo, K. E., Emelue, C. K., & Egharevba, R. K. A. (2018). Response of sweet potato to fertilizer placement methods in a tropical ultisol. *Journal of Agricultural Science and Practice*, *3*(2), 40–47.

Lebot, V. (2009). *Tropical Root and Tuber Crops: Cassava, Sweet Potato, Yams and Aroids*. CAB International.

Li, C., Wu, Y., Liu, X., Zhang, H., & Zhou, W. (2021). Nitrogen and phosphorus fertilization effects on soil microbial biomass and enzyme activities in a subtropical forest. *Applied Soil Ecology*, *166*, 104033.

Mahanta, D., Mishra, B. B., & Adhikary, N. (2018). Integrated nutrient management effects on soil enzyme activities and crop productivity in maize–mustard cropping system. *Archives of Agronomy and Soil Science*, *64*(12), 1779–1791.

Makinde, E. A., Ayoola, O. T., & Akande, S. R. (2011). Soil nutrient changes and maize yield following organomineral fertilization in a tropical rainforest soil. *Archiv für Agronomie und Bodenkunde*, *57*(3), 257–268.

Margalef, O., Alcañiz, J. M., & Alcañiz-Martínez, M. (2017). Soil enzyme activity and carbon cycling under different land-use types. *Science of The Total Environment*, *579*, 1640–1649.

Nannipieri, P., Trasar-Cepeda, C., & Dick, R. P. (2012). Soil enzyme activity: A brief history and biochemistry as a basis for appropriate interpretations and meta-analysis. *Biology and Fertility of Soils*, *48*(5), 503–515.

Ndubuisi-Nnaji, U. U., Eze, P. C., & Chukwu, L. I. (2015). Influence of poultry manure on soil enzyme activities and maize yield in a degraded ultisol. *African Journal of Biotechnology*, *14*(15), 1265–1271.

Ndung'u, J. N., Vanlauwe, B., & Giller, K. E. (2012). Yield and profitability of sweet potato in response to nitrogen and phosphorus application on smallholder farms in Kenya. *Experimental Agriculture*, *48*(3), 421–435.

Nwite, J. C. (2016). Effects of combined use of organic and inorganic fertilizers on soil properties and yield of maize in an acid ultisol. *Journal of Soil Science and Environmental Management*, *7*(1), 1–8.

Nyarko, K. O., Adewoyin, S. D., & Amujoyegbe, B. J. (2022). Effects of poultry manure, NPK fertilizer and their combinations on growth and yield of sweet potato. *Journal of Plant Nutrition*, *45*(14), 2097–2111.

Odebode, S. O., Afolabi, C. G., & Alade, M. A. (2016). Agronomic performance and adaptability of selected sweet potato (*Ipomoea batatas* L.) varieties in Southwestern Nigeria. *Nigerian Journal of Horticultural Science*, *21*(1), 23–29.

Okon, P. B., Effiong, G. S., & Udoh, D. J. (2019). Effects of organic and inorganic fertilizers on the yield and quality of sweet potato in Akwa Ibom State, Nigeria. *Journal of Agricultural Science and Practice*, *4*(2), 48–54.

Olander, L. P., & Vitousek, P. M. (2000). Regulation of soil phosphatase activity by temperature and phosphorus availability. *Soil Biology and Biochemistry*, *32*(12), 1797–1805.

Rahman, M. M., Islam, M. R., Islam, M. S., & Rahman, M. M. (2020). Integrated nutrient management: Effects on soil enzyme activities, nutrient availability and maize yield. *Journal of Soil Science and Plant Nutrition*, *20*(4), 1888–1900.

Rocabruna, A., Alcañiz, J. M., & Margalef, O. (2024). Long-term effects of organic and inorganic amendments on soil enzyme activities in a Mediterranean agricultural soil. *Science of The Total Environment*, *911*, 169002.

Sharma, P., Abrol, V., & Vig, S. (2011). Effect of organic manures and inorganic fertilizers on soil enzyme activities and productivity of maize–wheat cropping system. *Journal of Plant Nutrition*, *34*(15), 2200–2212.

Siebielec, S., Siebielec, G., & Stuczyński, T. (2021). The impact of long-term mineral and organic fertilization on soil enzyme activities: A meta-analysis. *Applied Soil Ecology*, *159*, 103848.

Soil Survey Staff. (2014). *Keys to Soil Taxonomy* (12th ed.). United States Department of Agriculture, Natural Resources Conservation Service.

Solangi, M. A., Solangi, K. A., Jamro, M. A., & Tunio, S. D. (2024). Effect of integrated application of chemical fertilizer and animal manure on soil biological properties and cotton yield. *Archives of Agronomy and Soil Science*, *70*(4), 486–500.

Tabatabai, M. A., & Bremner, J. M. (1969). Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry*, *1*(4), 301–307.

Tel, D. A. (1984). *Soil and Plant Analysis*. International Institute of Tropical Agriculture (IITA).

Turner, B. L., Frossard, E., & Baldwin, B. C. (2013). The role of phosphatases in soil phosphorus cycling. In B. L. Turner, E. Frossard, & Baldwin, B. C. (Eds.), *Phosphorus, Ecology and Global Change* (pp. 37–58). Springer, Dordrecht.

Vanlauwe, B., Bationo, A., Chivenge, P., & Giller, K. E. (2010). Integrated soil fertility management: operational definition and its application in African smallholder systems. *Field Crops Research*, *116*(3), 242–250.

Woolfe, J. A. (1992). *Sweet Potato: An Untapped Food Resource*. Cambridge University Press.

Zhang, Y., Liu, Y., Zhang, X., & Li, C. (2022). Long-term effects of inorganic and organic fertilization on soil enzyme activities and microbial community composition. *Frontiers in Environmental Science*, *10*, 870404.