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Organomineral Fertilizer IGOF as a Climate-Smart Alternative to NPK for Soil pH Correction, Grain Yield, and Nutritional Quality in Maize (Zea mays L.) Production in Kaduna State, Nigeria

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Abstract

Rising fertilizer prices, widespread soil acidity, and thin margins are pushing Nigerian smallholders out of maize production, while chemical fertilizers alone rarely correct the soil constraints limiting yield. We tested whether Instant Growth Organic Fertilizer (IGOF), a company-formulated organomineral fertilizer from valorized agro-industrial residues, could outperform NPK, in a replicated field trial in Kaduna State, Nigeria, comparing IGOF and NPK applied alone and blended with poultry manure (1:3) for effects on soil pH, grain yield, grain composition, and cost–benefit performance. IGOF + poultry manure produced the largest, statistically significant correction of soil acidity, raising post-harvest soil pH by 1.30 units (6.4 to 7.7), whereas NPK alone left acidity uncorrected (− 0.10 units) despite its high cost. IGOF alone gave the highest grain yield (10.27 ± 2.89 t ha⁻¹), though not significantly above NPK, and shifted grain composition toward higher lipid (4.56 vs 4.38%, $p = 0.003$) and protein (16.10 vs 12.62%, $p < 0.001$) at the expense of carbohydrate — a nutritionally favourable tilt attributable to the organomineral input. Economically, NPK alone was not viable at typical Nigerian hand-tillage density, returning a net loss of ₦1,310,576 ± 980,384 ha⁻¹, while IGOF + poultry manure was most profitable (₦1,518,057 ± 535,411 ha⁻¹) and IGOF alone a close second (₦1,395,339 ± 920,169 ha⁻¹). These results identify IGOF, particularly blended with poultry manure, as a soil-correcting, nutrition-enhancing, profit-positive alternative to NPK for maize on acidic soils, supporting wider evaluation as a scalable, waste-valorized input for smallholder agriculture in Nigeria and comparable Guinea Savanna settings. By converting agro-industrial waste into a soil-restorative, climate-smart fertilizer that raises smallholder income and food quality, these findings contribute direct field evidence toward United Nations Sustainable Development Goals 2 (Zero Hunger), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land).

1. Introduction

The circular economy (CE) framework — a production and consumption model organized around the recovery and reuse of materials rather than their disposal — was introduced by the European Commission as a response to mounting environmental and social costs of a linear economy [1]. The scale of the underlying waste problem is substantial: global waste generation is estimated at 3.5 million Mg per day, a figure projected to double by 2050 and triple by 2100 [2], with growth concentrated in sub-Saharan Africa and South Asia even as it plateaus in Europe [2]. Because much of this waste is a reservoir of recoverable nutrients, closing the loop on its reuse — rather than allowing it to be dissipated as pollution — has become a policy priority within the EU and beyond [3–5]. This priority sits squarely within the United Nations 2030 Agenda for Sustainable Development: closing nutrient loops through waste recovery and reuse is the explicit target of SDG 12 (Responsible Consumption and Production, Target 12.5), while the emissions avoided by diverting biomass from open burning and landfill speak directly to SDG 13 (Climate Action).

This policy priority collides with a fertilizer industry that has changed little in over a century. Production remains anchored to non-renewable resources — nitrogen fertilizers via the fossil-fuel-dependent Haber–Bosch process, phosphorus fertilizers via finite phosphate-rock deposits [6] — even as consumption keeps rising: EU nitrogen, phosphate (P_2O_5), and potash (K2O) use grew from 10.4, 2.4, and 2.7 Mt in 2010 toward a projected 10.8, 2.7, and 3.2 Mt by 2019/2020, respectively. Chojnacka *et al*. [5] attribute this inertia to structural rather than technical barriers: because demand for conventional fertilizer has historically outstripped supply, producers have had little economic incentive to valorize renewable feedstocks, and the large, centralized scale of production facilities is poorly matched to the distributed, less-standardized nature of biomass waste streams. Bio-based feedstocks are also bulky and prone to anaerobic decay in transport, which is why on-site or near-site valorization — rather than retrofitting existing centralized plants — is increasingly proposed as the more practical route to a bio-based fertilizer sector [5].

Circular economy principles — recommended by both the EU and the European Industrial Organization of Fertilizers — call for substituting a share of conventional fertilizer raw materials with residual biomass, including post-harvest crop residues, livestock and slaughter waste, and food-processing by-products [4]. The EU projects that bio-waste could replace up to 30% of the inorganic fertilizer currently used [4], and the transition from a fossil- to a bio-based economy will require recovering nutrients from these waste streams rather than treating them as an externality [7].

The environmental case for this shift is direct: an estimated 30–50% of applied fertilizer nutrients are lost to leaching or volatilization rather than taken up by crops, contributing to groundwater contamination and soil degradation, with losses reducible where fertilizer composition, release rate, and application are matched to soil type and cropping system [8]. Waste-derived alternatives offer one route to reducing this loss while recovering value from residues that would otherwise be discarded — for example, post-extraction plant residues enriched with micronutrient ions (Cu, Mn, Zn) to produce bio-based micronutrient fertilizers [9–11].

Realizing this potential depends on field-level validation. New fertilizer technologies must be tested in situ for their effects on soil quality, nutrient-use efficiency, and crop yield relative to conventional NPK references [6, 12], and on the farmer-adoption factors — price, labor demand, and supporting infrastructure for collection, storage, and distribution — that ultimately determine whether bio-based products can displace chemical fertilizer in practice. Wang *et al.* [8] found that farmer-association membership, subsidy access, and farm size all shape uptake of organic alternatives, while Tur-Cardona *et al.* [13] reported that price parity is central: bio-based fertilizers gain traction with farmers mainly when priced substantially (around 65%) below chemical equivalents, alongside high nutrient bioavailability and adequate hygienization.

Beyond nitrogen, the phosphorus industry faces its own unresolved problems: depleting non-renewable phosphate-rock reserves and large volumes of phosphogypsum by-product — produced at roughly twice the mass of the phosphoric acid it accompanies — for which storage remains a persistent environmental liability [5]. Despite growing scientific and political attention, circular-economy principles of reuse, valorization, and recycling of natural cycles have so far been applied only fragmentarily within the fertilizer sector, in part because the industry has historically pursued process efficiency (higher yields, lower input and energy costs) rather than product innovation, leaving little pressure to adopt renewable raw-material bases [5].

Efforts to convert agricultural and agro-industrial residues into fertilizing products have gained traction as a practical response to both the European Union's circular economy agenda and the global imperative to reduce open burning of agricultural waste and its associated greenhouse gas emissions. EU circular economy policy, endorsed by the European Commission and the European Industrial Organization of Fertilizers, calls for substituting fertiliser raw materials with residual biomass — including post-harvest residues, livestock and slaughter waste, and food-processing residues [5], a direction formally codified in Regulation (EU) 2019/1009, which for the first time opened the EU single market to organic and organo-mineral fertilising products derived from such secondary raw materials [14]. Within this framework, biosorption-based valorization has been widely explored, with berry-processing seed residues [9] and spent mushroom substrate [11] both converted into micronutrient-enriched organomineral fertilizers, the latter validated in replicated field trials on maize where yield was 11.5% higher than an untreated control and statistically comparable to a commercial micronutrient reference fertilizer. Complementing the biosorption route, Gideon, Duniya, and James [15] demonstrated an alternative, rapid chemical valorization pathway, converting eleven types of dry agricultural plant residues into organomineral biofertilizers (Fertilizers A, B, and C) via acid and alkali digestion combined with wood-ash amendment, and reported that maize treated with the resulting product achieved a maximum plant height of 171.45 cm and grain yield of 316.24 g, outperforming both NPK 20:10:5 fertilizer (134.0 cm; 287.38 g) and rabbit manure (121.92 cm; 91.72 g); however, only one of the three biofertilizer variants was chemically

characterized, dosing across treatments was not nutrient-equivalent, and phytotoxic effects observed with one variant required corrective, unplanned pH buffering with calcium hydroxide during the trial, underscoring both the promise of chemical valorization as a faster alternative to biosorption and the need for more rigorously standardized formulation and characterization protocols going forward.

Complementing peer-reviewed valorization research, Sustainable Organic Innovations Limited (Kaduna, Nigeria) has developed a four-stage process — collection, processing, formulation, and application — for converting agricultural waste such as maize stalks, rice husks, and sorghum stalks into an organomineral fertilizer, rather than allowing this biomass to be burned or left to rot [16]. According to the company, its processing techniques break down these residues while preserving nutrient integrity, after which fertilizer blends are formulated to target the nutrient requirements of different crop types; the company states that the resulting products are designed to work with existing farming equipment and practices. This process underpins the development of IGOF, an organomineral fertilizer derived from valorized agro-industrial residues that forms the basis of the present study. The company positions three benefits as central to its approach: soil regeneration through the reintroduction of essential nutrients, waste reduction by diverting agricultural residues from open-field burning, and economic opportunity by reducing farmers' reliance on expensive chemical fertilizers while converting previously discarded waste into a new value stream. These company-stated aims align with the broader circular-economy and climate-mitigation logic embedded in EU policy instruments such as Regulation (EU) 2019/1009; the present trial provides an independent, field-based test of whether IGOF delivers on them in a Nigerian agricultural context.

Maize (*Zea mays* L.) is one of the most widely cultivated cereal crops in the world, valued as a staple food, livestock feed, and industrial raw material across diverse agro-ecological zones [17]. Its high productivity per hectare, broad climatic adaptability, and multiple end-uses have made it central to global food security, particularly across sub-Saharan Africa, where it increasingly rivals rice and wheat in dietary importance [17]. Beyond its nutritional value, maize is recognized as an unusually nutrient-exhaustive crop: it demands substantial and balanced supplies of nitrogen, phosphorus, and potassium to achieve optimal grain fill, and its yield response is highly sensitive to soil fertility status [18]. This sensitivity makes maize a preferred test crop for comparative fertilizer trials, since differences between nutrient sources and formulations are expressed clearly and consistently in its growth and yield outcomes [15].

However, the fertilizer-dependent production model underpinning maize agriculture faces mounting pressure. Global fertilizer prices have repeatedly exceeded historical projections, driven by fossil-energy dependence, phosphate-rock depletion, and recurrent geopolitical shocks, with attendant yield reductions projected under high-price scenarios [19, 20]. Compounding this, prolonged reliance on inorganic, particularly ammonium-based, fertilizers accelerates soil acidification, depletes exchangeable base cations, and diminishes microbial diversity, progressively eroding the very soils on which maize depends [21–23].

These converging pressures carry acute consequences for Africa, the world's fastest-growing continent by population, and especially for Nigeria, which remains both Africa's most populous nation and the most populous Black nation on Earth, with over 240 million people to feed [24, 25]. Without accessible, soil-restorative fertilization alternatives, sustaining maize productivity across the region will become an increasingly urgent agronomic and policy challenge.

These agronomic pressures map directly onto the interlinked United Nations Sustainable Development Goals (SDGs) that frame this study. Converting agricultural residues that would otherwise be openly burned into a soil-restorative organomineral fertilizer exemplifies the resource-recovery ambitions of SDG 12 (Responsible Consumption and Production) and avoids the emissions penalty that open burning imposes on SDG 13 (Climate Action); correcting the soil acidity and fertility constraints that limit smallholder maize yields speaks to SDG 2 (Zero Hunger) and to SDG 15

(Life on Land, Target 15.3 on land degradation neutrality); and testing whether a locally produced input can out-compete imported NPK on cost and profitability engages SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) as they bear on smallholder livelihoods. Generating field evidence on IGOF's agronomic, nutritional, and economic performance relative to NPK therefore speaks directly to Nigeria's progress on this cluster of goals.

Against this backdrop, we conducted a replicated field trial in Kaduna State, Nigeria, to evaluate Instant Growth Organic Fertilizer (IGOF) — a company-formulated organomineral fertilizer derived from valorized agro-industrial residues — as a climate-smart alternative to conventional inorganic NPK fertilizer for maize production.

1.1 Aim and Objectives

Aim

This study aimed to evaluate Instant Growth Organic Fertilizer (IGOF), a company-formulated organomineral fertilizer derived from valorized agro-industrial residues, as a climate-smart, soil-restorative alternative to conventional inorganic NPK fertilizer for maize production on acidic tropical soils in Kaduna State, Nigeria, thereby generating field evidence directly relevant to United Nations Sustainable Development Goals 2 (Zero Hunger), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land).

Objectives

The specific objectives of the study were to

1. Compare maize growth, and cob and grain yield under IGOF and NPK fertilization, applied alone and in combination with poultry manure;
2. Characterize the physicochemical properties and trace-metal content of the IGOF fertilizer; and
3. Compare the proximate (nutritional) composition of grain harvested from IGOF- and NPK-fertilized plots.

Together, these outcomes provide field-validated agronomic and nutritional evidence for the potential of IGOF as a locally produced, waste-derived substitute for chemical fertilizer in a Nigerian smallholder context.

2. Materials and Methods

2.1 Materials

All reagents, chemicals, and glassware used for the elemental, physicochemical, trace-metal, and proximate analyses in this study were of analytical (AnalaR) grade. Analyses were carried out at the Institute for Agricultural Research (IAR) and the Chemistry Multiuser Laboratory, Ahmadu Bello University, Zaria, Kaduna State. A complete inventory of the specific reagents, instruments, and equipment used, with manufacturers where available, is provided in Supplementary Table S1.

2.2 Study Area

The field trial was conducted at Tsuanin Kura GRA (adjacent to Vinco Block), Dikko Road, Sabon Tasha, Kaduna North Local Government Area, Kaduna State, Nigeria, on a partially developed residential plot on which foundation/cover crops were already established pending full site development. Precise site geolocation (corner coordinates, Points 1–4) is given in Fig. 1. The area lies within Nigeria's Guinea Savanna agro-ecological zone, characterized by a unimodal rainy season (approximately April–October) and a distinct dry season. The maize growing period for this trial ran from 18 May 2026 to August 2026, coinciding with the onset and progression of the rainy season.

2.3 Sampling

Instant Growth Organic Fertilizer (IGOF) was sourced from SOI Limited, Water Intake Road, Maigero, along the Zaria Expressway, Kaduna. Two inorganic NPK fertilizer brands — Golden fertilizer (NPK 20:10:10) and Matrix fertilizer (NPK 20:10:5) — were purchased at Gumi Central Market, Kaduna North, Kaduna metropolis, Kaduna State. Maize seeds (a local variety of mixed white and yellow corn) were sourced from Dikko Road, Tsuanin Kura GRA (adjacent to Vinco Block), Sabon Tasha, Kaduna North, Kaduna State.

2.4 Trial Farm Design

The trial was conducted on an existing, partially developed plot on which foundation/cover crops were already growing pending full development of the land. Four plots, each measuring 6 ft × 15 ft, were laid out side by side, with a planting density of 18–20 plants per plot (2 plants per hole), and the same four-treatment layout was duplicated on a second, identically sized set of plots immediately adjacent within the same location — giving two independently planted field replicates per treatment (eight plots in total: four treatments × two plot-replicates). Measurements from the matching plot-pair for each treatment were pooled when compiling the results reported in Section 3. This relatively compact plot size and density were adopted, rather than a larger open layout, because of community security concerns requiring the trial to remain visible.

2.5 Fertilizer Sample Preparation and Application

The two NPK fertilizer brands, Golden (20:10:10) and Matrix (20:10:5), were mixed in a 1:1 ratio and used as the single "NPK" fertilizer treatment throughout the study. This NPK blend was then combined with poultry manure at a ratio of 1:3 to form the NPK + poultry manure treatment. IGOF was likewise combined with poultry manure at 1:3 to form the IGOF + poultry manure treatment. The four resulting treatments were applied to the four plots in the following order, from left to right (each plot 6 ft wide × 15 ft long; Figs. 1 and 2):

Fertilizers were applied three times per plot, at a fixed rate per application for each treatment: NPK + poultry manure, 14.85 ± 0.15 g; NPK, 26.4 ± 0.1 g; IGOF, 10.4 ± 0.15 g; IGOF + poultry manure, 10.85 ± 0.13 g. The first application was made two weeks after germination, the second two weeks after the first application, and the third three weeks after the second application. The growing period ran from 18 May 2026 to August 2026 at Tsuanin Kura GRA, Sabon

2.6 Harvesting and Yield Analysis

In every plot, only one maize plant produced two cobs, and cob formation across the plot overall was sparse and irregularly seeded. From each plot, three cobs — the biggest, medium, and smallest — were selected from different positions within the plot, air-dried, and then oven-dried at 45°C for 5 days. Seeds were removed from the cobs, counted, and the average recorded; this was used to estimate grain yield (t ha^{-1}) using the formula:

Grain yield (t ha^{-1}) = [mean seed weight cob^{-1} (g) × plant density (plants ha^{-1})] ÷ 1,000,000 … ……..**Eq. (1)**

Profit relative to fertilizer cost/input and output at the prevailing maize grain price was estimated using the formula:

Net profit / (loss) ha^{-1} (₦) = Output/revenue ha^{-1} (₦) − Input cost ha^{-1} (₦) …… **Eq. (2)**

Full derivations and results of both equations are presented in Section 3 (Results).

2.7 IGOF Fertilizer Analysis, and NPK and IGOF Maize Grain Proximate Analysis

The IGOF sample was packaged in a dark glass bottle and taken to the Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, for elemental, physicochemical, and trace-metal determination. Fifty grams (50 g) each of NPK- and IGOF-fertilized maize grain were ground, pulverized, and sieved, then packaged in dark glass bottles. Proximate analysis was carried out on each sample at IAR, ABU Zaria, using the standard analytical procedures detailed in the following subsections.

2.8 Trace-Metal and Physicochemical Analysis of IGOF Fertilizer

At Chemistry Multiuser Laboratory, ABU Zaria, the IGOF sample was analysed for elemental composition (including N, P, and K), physicochemical properties (pH and bulk density), and trace-metal concentrations using the Institute's standard analytical protocols. Heavy-metal analysis was conducted using Microwave Plasma-Atomic Emission Spectroscopy (MP-AES 4200) with laboratory-grade hydrochloric and nitric acids from the German supplier Riedel–de Haën. Samples were prepared following a strict pre-treatment protocol, including cleaning, immersion in nitric acid, and drying, before being weighed, digested, and filtered. The actual concentration (mg/kg) was calculated using Eq. (3) below, following heating, cooling, and dilution with deionized water to ensure precision and consistency [26].

Actual Concentration = (Instrument Reading ×Dilution Factor)/Sample Weight …….. **Eq. (3)**

2.9 Proximate Analysis of Maize Grain

Proximate composition of maize grain harvested from IGOF- and NPK-fertilized plots was determined in triplicate at IAR using standard AOAC-based procedures, as follows.

Determination of moisture content [27]

Aluminum or plastic dishes were washed and dried to a constant weight in an oven at 100°C, then removed and cooled in a desiccator and weighed (W_1). Two grams of the powdered sample were placed in the weighed moisture dish (W_2). The dish containing the sample was kept in the oven for approximately 3 hours, then removed and cooled in the desiccator and weighed (W_3). Percentage moisture was calculated as:

Moisture (%) = $[(W_2 - W_3) / (W_2 - W_1)] \times 100$ …… **Eq. (4)**

Determination of ash content

Crucibles were cleansed, dried in the oven, cooled in a desiccator and weighed (W_1). Two grams of the powdered sample were placed in the crucible and weighed (W_2). Samples were ashed in a muffle furnace at approximately 550°C, then cooled in a desiccator and weighed (W_3). Percentage ash was calculated as:

Ash (%) = $[(W_3 - W_1) / (W_2 - W_1)] \times 100$ …… **Eq. (5)**

Determination of crude fibre content

Two grams of sample were placed in a beaker containing 1.2 mL H_2SO_4 per 100 mL solution and boiled for approximately 30 minutes; the residue was filtered and washed with hot water, then transferred to a beaker containing 1.2 g NaOH per 100 mL solution and boiled for a further 30 minutes. The residue was washed with hot water, dried in an oven, and weighed (C_2), then incinerated in a furnace at approximately 550°C, cooled, and weighed (C_3). Percentage fibre was calculated as:

Fibre (%) = $[(C_2 - C_3) / W] \times 100$ …… **Eq. (6)**

Determination of lipid (fat) content

A 250 mL boiling flask was oven-dried, transferred to a desiccator and cooled. An empty filter-paper thimble was weighed (W_1), and 2 g of sample was weighed into the labelled thimble (W_2). The boiling flask was charged with petroleum spirit (N-hexane) and the Soxhlet apparatus assembled, with reflux continued for 8 hours. The extracted flask was then oven-dried, cooled in a desiccator, and weighed (W_3). Percentage fat was calculated as:

Fat (%) = $[(W_2 - W_3) / (W_2 - W_1)] \times 100$ ..... **Eq. (7)**

Determination of protein content

Protein was determined by the micro-Kjeldahl method, comprising digestion, distillation, and titration stages. For digestion, 0.5–2 g of sample was weighed into a Kjeldahl flask with a copper catalyst and 15 mL concentrated H_2SO_4, heated in a fume cupboard until the solution turned green, cooled, and diluted to 100 mL with distilled water. For distillation, the Markham apparatus was steamed through for 15 minutes; 10 mL of the digest was pipetted into the apparatus with 10 mL of 40% NaOH, and steamed through for 5–7 minutes to collect the distillate (30–40 mL) into a receiving flask containing 10 mL boric-acid indicator. The distillate was titrated against N/100 (0.01 N) hydrochloric acid, with a reagent blank run alongside every batch. Percentage protein was calculated as:

Protein (%) = [(final titre − initial titre − blank) × 1.4 / sample weight] × 6.25 ..... **Eq. (8)**

Determination of carbohydrate content [28]

Carbohydrate content was obtained by difference, after estimating all other proximate fractions:

Carbohydrate (%) = 100 − (% moisture + % ash + % protein + % fat + % fibre) ..... **Eq. (9)**

2.11 Statistical Analysis

Data are presented as mean ± standard deviation (SD) of triplicate (n = 3) determinations unless otherwise stated; these triplicates were pooled across each treatment's two field-plot replicates (Section 2.4) rather than drawn from a single plot, though plot identity itself was not entered as a separate factor in the analyses below (see Section 4, Conclusion, for the resulting limitation). For proximate composition, where exactly two independent treatment groups (IGOF vs NPK) were compared, group means were tested using an independent-samples Student's t-test, with Levene's test applied beforehand to confirm homogeneity of variance and justify use of the pooled-variance form. For comparisons among the four applied fertilizer treatments (IGOF, IGOF + poultry manure, NPK, NPK + poultry manure) — including material pH, bulk density, and the soil pH correction factor — one-way analysis of variance (ANOVA) was used, followed by Tukey's honestly significant difference (HSD) post-hoc test for pairwise comparisons where the overall F-test was significant. Differences were considered statistically significant at $p < 0.05$. Untreated reference materials (baseline soil, raw poultry manure) were excluded from inferential comparisons and are reported descriptively only.

3. Results and Discussion

3.1 Field Performance and the Basis of IGOF's Nutrient Delivery

In the field, NPK-fertilized maize consistently appeared visually greener while foliage remained unremoved, an unsurprising response to its high, rapidly available nitrogen load, applied here at a rate well above the conventional per-plant threshold (Table 3, application rates). What is more striking is that IGOF, applied at a substantially lower NPK-equivalent rate, matched or exceeded NPK's agronomic performance on almost every downstream measure examined in this section. We attribute this to IGOF's broader elemental base: alongside nitrogen, phosphorus and

potassium, its biomass-derived organomineral matrix carries calcium, magnesium and silicon, together with organic matter that supports soil microbial activity and water-holding capacity. These secondary elements do not register in a simple NPK-ratio comparison, but they plausibly underlie IGOF's comparatively strong yield, pH-correcting and grain-quality outcomes reported below, consistent with the broader principle that organomineral inputs act through soil biological and structural pathways in addition to direct nutrient supply [29].

In terms of general field appearance, maize development across the four trial portions was broadly similar for most of the growing season; the most conspicuous visual difference was the greener canopy of NPK-fertilized maize, consistent with its high, rapidly available nitrogen supply, applied here at more than 15 g per plant per application — well above the conventional per-plant threshold (Table 3, application rates). On nutrient content alone, NPK might therefore have been expected to outperform IGOF outright. That IGOF nonetheless matched or exceeded NPK's downstream agronomic performance despite its comparatively low NPK-equivalent loading is better explained by its broader elemental base than by its NPK ratio in isolation: as Table 1 below shows, IGOF's biomass-derived matrix supplies calcium, magnesium, silicon and other trace elements alongside substantial organic matter, which plausibly underlies the soil microbial support, water-retention capacity and modest pH adjustment associated with IGOF treatments (Table 2).

IGOF Nutrient, Physicochemical and Trace-Metal Composition Compared with NPK

Table 1

presents the mean nutrient, physicochemical and trace-metal composition of two IGOF fertilizer samples (labelled FO and FN on the laboratory sheet), alongside the declared composition of the NPK blend used in this trial. Trace-metal concentrations, originally reported in mg kg^{-1} (ppm), were additionally converted to percentage (1% = 10,000 mg kg^{-1}) for direct comparison with NPK, whose composition is reported by the manufacturer as a single declared percentage per nutrient, with no replicate or SD available. Because NPK values represent a single manufacturer specification rather than replicated measurements, no formal statistical test of significance was applied between IGOF and NPK; the comparison below is descriptive.

Parameter	IGOF Mean ± SD (%)	NPK (%)
A. Macronutrients and physicochemical properties (%, unless stated)		
Nitrogen, N (%)	**1.10 ± 0.08**	20
Available phosphorus, Pas (%)	**0.24 ± 0.16**	—
Available P_2O_5, Pas (%)	**0.56 ± 0.36**	10
Water-soluble phosphorus, Pws (%)	**0.09 ± 0.01**	—
Water-soluble P_2O_5, Pws (%)	**0.21 ± 0.04**	—
Available potassium, Kas (%)	**0.54 ± 0.06**	—
Available K_2O, Kas (%)	**0.65 ± 0.06**	10
Water-soluble potassium, Kws (%)	**0.32 ± 0.05**	—
Water-soluble K_2O, Kws (%)	**0.38 ± 0.06**	—
Sulphur, S (%)	**0.028 ± 0.008**	—
Sulphate, SO_4 (%)	**—**	11.8
Chloride, Cl (%)	**—**	8
Calcium oxide, CaO (%)	**—**	NA
Organic carbon, O.C (%)	**37.51 ± 10.91**	—
Organic matter, O.M (%)	**64.66 ± 18.81**	—
Moisture / WHC (%)	**19.67 ± 8.96**	—
pH	**6.12 ± 0.03**	—
Electrical conductivity, EC (dS m^{-1})	**1.30 ± 0.14**	—
B. Trace / heavy metal content		
Cadmium, Cd (mg kg^{-1}) / (%)	**0.0085 ± 0.0064 / 0.00009 ± 0.00006%**	—
Cobalt, Co (mg kg^{-1}) / (%)	**0.116 ± 0.045 / 0.0012 ± 0.0004%**	—
Copper, Cu (mg kg^{-1}) / (%)	**0.072 ± 0.022 / 0.0007 ± 0.0002%**	—
Iron, Fe (mg kg^{-1}) / (%)	**3.713 ± 1.042 / 0.0371 ± 0.0104%**	—
Manganese, Mn (mg kg^{-1}) / (%)	**2.264 ± 0.855 / 0.0226 ± 0.0085%**	—
Nickel, Ni (mg kg^{-1}) / (%)	**0.044 ± 0.020 / 0.0004 ± 0.0002%**	—

Parameter	IGOF Mean ± SD (%)	NPK (%)
A. Macronutrients and physicochemical properties (%, unless stated)		
Lead, Pb (mg kg⁻¹) / (%)	**NA**	—
Zinc, Zn (mg kg⁻¹) / (%)	**0.835 ± 0.505 / 0.0083 ± 0.0050%**	1
Chromium, Cr (mg kg⁻¹) / (%)	**0.973 ± 0.648 / 0.0097 ± 0.0065%**	—

Table 1. Composition of IGOF (mean ± SD, n = 2 samples) and NPK fertilizer. “NA” = not applicable / not declared by the manufacturer. Pws = water-soluble; Pas = available (extractable); Kws = water-soluble potassium; Kas = available (extractable) potassium. NPK composition (N-P_2O_5-K_2O = 20-10-10, plus SO_4, Cl, Zn) reflects the declared grade on the product specification, not a replicated laboratory analysis.

On a nutrient basis, NPK supplies far higher concentrations of the primary macronutrients per unit weight than IGOF: 20% N versus IGOF's 1.10 ± 0.08% N, and roughly 10% P_2O_5 and K_2O versus IGOF's available P_2O_5 (0.56 ± 0.36%) and available K_2O (0.65 ± 0.06%). This is expected, since NPK is a concentrated mineral fertilizer blend, whereas IGOF is a bulkier, organic, agro-residue-based material; notably, even the substantially higher per-plant application rate used for NPK in this trial (26.4 ± 0.1 g vs IGOF's 10.4 ± 0.15 g per application; Table 3) still did not translate into superior field performance (Section 3.1), consistent with IGOF's contribution operating through pathways beyond simple NPK-equivalent nutrient supply.

IGOF, however, contributes substantial organic carbon (37.51 ± 10.91%) and organic matter (64.66 ± 18.81%), which NPK does not supply at all — this is IGOF's main soil-conditioning value beyond its NPK-equivalent nutrient content, consistent with the improved soil pH buffering observed for IGOF-based treatments in the soil pH analysis (Section 3.2).

Trace and heavy-metal levels in IGOF were low across both samples: expressed as a percentage of the material, all metals were below 0.04%, with iron (0.037 ± 0.010%) and manganese (0.023 ± 0.009%) the most abundant, and cadmium, cobalt, copper and nickel present only at trace (< 0.002%) levels. Zinc in IGOF (0.0083 ± 0.0050%) was well below the 1% Zn declared for NPK. No heavy-metal data were available for NPK from the supplier specification, so a direct metal-for-metal comparison could not be completed for that material.

Implications for Soil pH Correction and Field Performance

Correcting soil acidity in resource-poor smallholder settings is rarely straightforward: sulfur- and lime-based amendments recommended in the wider literature are agronomically effective but are frequently too expensive and too logistically demanding — in sourcing, transport and correct application — for the average Nigerian farmer [30]. Against this backdrop, the pH correction achieved by IGOF-based treatments in the present trial (Section 3.2, Table 2) is instructive. Applied alone, IGOF corrected post-harvest soil pH by only a modest 0.3 units after three applications, leaving the soil comparatively more vulnerable to continued acidity than the blended treatments; combining either IGOF or NPK with poultry manure at 1:3 drastically reduced this vulnerability by pushing soil reaction into a mildly alkaline zone, an effect that was most pronounced for IGOF + poultry manure, which raised soil pH from the acidic baseline of 6.4 to 7.7. This suggests that, where sustained soil correction rather than single-season yield is the priority, poultry manure — a cheap, locally available input — is effectively the enabling ingredient that unlocks IGOF's soil-remediating potential. Given how extensively soil acidity has degraded productive cropland and constrained maize output across Nigeria, an affordable, repeatable correction pathway of this kind, applied over successive

cropping seasons, could meaningfully alleviate the problem at a scale that conventional lime- or sulfur-based recommendations have struggled to reach.

3.2 pH and Bulk Density of Fertilizer Materials, Soil, and Soil pH Correction under Different Fertilizer Treatments

Soil and poultry manure (untreated reference materials) were excluded from the statistical comparison. Statistical testing (one-way ANOVA with Tukey HSD post-hoc, reconstructed from mean, SD and n = 3 replicates per group) was carried out only across the four actually-applied treatments: IGOF, IGOF + poultry manure (1:3), NPK, and NPK + poultry manure (1:3). Means within a row followed by the same superscript letter are not significantly different at $p < 0.05$.

Table 2
pH and bulk density of fertilizer materials, soil, and soil pH correction under different fertilizer treatments. †Baseline soil pH (6.4 ± 0.30) is shown for reference in the post-harvest row to illustrate the starting point before treatment; it is not itself a post-harvest measurement. ‡Soil pH correction factor = post-harvest soil pH (3 cm from roots) − baseline soil pH (6.4 ± 0.30); a positive value indicates the treatment raised soil pH relative to the untreated baseline, a negative value indicates it lowered soil pH. "—" = not applicable (soil and poultry manure were not applied as treatments, so no post-harvest or correction-factor value exists for them). Values are mean ± SD; superscript letters denote Tukey HSD groupings among the four applied treatments only ($p < 0.05$).

Parameter	Soil (baseline)	Poultry manure	IGOF	IGOF + poultry (1:3)	NPK	NPK + poultry (1:3)	ANOVA (4 treatments)
Bulk density (g cm⁻³)	1.50 ± 0.07	0.43 ± 0.01	0.40 ± 0.01	0.42 ± 0.02	1.10 ± 0.05	0.48 ± 0.03	$F_{3,8} = 345.4$, $p < 0.001$
Material pH (pre-application)	6.4 ± 0.30	8.1 ± 0.15	6.7 ± 0.20	7.3 ± 0.19	7.5 ± 0.16	7.9 ± 0.10	$F_{3,8} = 26.9$, $p < 0.001$
Soil pH (3 cm from roots, post-harvest)	6.4 ± 0.30†	—	6.7 ± 0.18	7.7 ± 0.17	6.3 ± 0.12	6.7 ± 0.10	$F_{3,8} = 49.9$, $p < 0.001$
Soil pH correction factor‡	—	—	+ 0.30 ± 0.35	+ 1.30 ± 0.35	−0.10 ± 0.32	+ 0.30 ± 0.32	$F_{3,8} = 9.6$, $p = 0.005$

Bulk density differed significantly among the four treatments ($F_{3,8} = 345.4$, $p < 0.001$): NPK alone was markedly denser (1.10 ± 0.05 g cm⁻³) than IGOF, IGOF + poultry and NPK + poultry, which formed a lighter, statistically similar group (0.40–0.48 g cm⁻³). Material pH differed significantly among treatments ($F_{3,8} = 26.9$, $p < 0.001$), rising in the order IGOF (6.7) < IGOF + poultry (7.3) < NPK (7.5) ≈ NPK + poultry (7.9), with IGOF + poultry and NPK statistically overlapping.

The soil pH correction factor — the shift in soil pH (measured 3 cm from the roots after harvest) relative to the untreated soil baseline of 6.4 — showed the clearest agronomic signal in the trial ($F_{3,8} = 9.6$, $p = 0.005$), and this is the clearest and most consequential result of the trial as a whole. Only IGOF blended with poultry manure (1:3) produced a soil pH correction that was both large and statistically robust, raising post-harvest soil pH by 1.30 units above baseline, to 7.7 — significantly outperforming every other treatment. IGOF applied alone produced a smaller but still positive correction (+ 0.30, to pH 6.7), as did NPK blended with poultry manure (+ 0.30, to pH 6.7). NPK applied alone, in contrast, left soil acidity essentially unaddressed, with a small, statistically non-significant decline of − 0.10. In practical terms, farmers using NPK alone in this trial paid the highest fertilizer bill (Table 7; see Section 3.6 below) without buying any improvement in the underlying soil constraint that limits long-run productivity.

This matters because acid soils remain one of the most under-addressed constraints on cereal productivity across sub-Saharan Africa: acid soils are estimated to depress yields on roughly 23% of the region's cropland, at an annual

cost of around US$6.0 billion, and while agricultural lime is the conventional remedy, it is frequently unavailable or unaffordable at the farm gate, and its profitability is highly site-specific [31]. Sulfur- and lime-based soil amendments recommended in the wider literature are similarly effective in principle but tend to be expensive and logistically demanding for the average Nigerian smallholder to source and apply correctly [30]. IGOF combined with a modest ratio of poultry manure offers a materially cheaper route to a comparable end: it delivers an organic-matter and buffering effect broadly analogous to a liming intervention, using inputs already familiar to, and locally available for, smallholder farmers. Because soil pH governs the solubility of phosphorus and several essential micronutrients (Fe, Mn, Zn), the correction achieved by IGOF + poultry manure should, if sustained across seasons, progressively relax a constraint that repeated NPK application on its own does not touch [30].

It is worth noting, however, that the treatment with the strongest pH correction (IGOF + poultry manure, to pH 7.7) did not produce the highest yield in this trial — that distinction belongs to IGOF alone, whose smaller pH shift (to 6.7) kept soil reaction closer to the range in which maize typically shows optimal nutrient uptake [30, 37] (compare Table 4, Section 3.4 below). This points to a genuine trade-off rather than a single ‘best’ treatment: IGOF alone maximizes short-term yield, while IGOF blended with poultry manure maximizes soil remediation, and the appropriate choice between them should depend on whether a farmer's more pressing constraint is this season's harvest or a legacy of accumulated soil acidity.

Fertilizer Dose and Soil pH as Direct Drivers of Maize Yield: Comparison with Published Literature

Table 3

situates the present trial (Group D) alongside comparable organic- and inorganic-fertilizer maize trials reported in the literature (Groups A–C). plant densisty was not capture as is not presented in some of the literature (Group A-C) although the table main purpose is to compare weight and tonnage of fertilizer applied to the yield gotten, to present a scenario where too much fertilizer or manure application may not necessarily translate to higher crop yield taking cognizance of soil pH also.

Manure Type / Treatment	Bulk Density (g/cm³)	Weight of 50,000 cm³ (kg)	Applied bags/tonne	Application method	Yield (t ha⁻¹)	Soil/product pH
Group A — Mahmood et al. [32]						
No fertilizer	—	—	—	—	1.19	5.3 / —
Farm Yard Manure	0.5	44	220/5	Incorporation into soil	4.5	— / 7.9
FYM + 5.7 bags NPK	—	44	374/8.5	Soil	8.0	7.6 / —
Poultry Manure (PM)	0.6	36	60	Soil, 120 g/plant	2.0	5.3 / 8.03
PM + 5.7 bags NPK	—	—	252/7	Soil application	8.43	— / 7.6
Sheep Manure (SM)	0.5	44	660/15	Soil	6.84	— / 7.6
SM + 5.7 bags NPK	—	—	352/8	Soil	8.2	— / 7.6
Cattle Manure (CM)	0.5	44	308/7	Incorporation into soil	4.4	— / 7.86
NPK (20:10:10)	—	—	6	Soil, 11.2 g/plant	1.74	5.3 / —
Group B — Bekolo Ndongo et al. [33]						
No fertilizer	—	—	—	—	2.8	—
Farm Yard Manure	—	44	704/16	Soil application	6.1	7.6 / —
Poultry Manure	—	36	468/13	Soil application	7.13	— / 7.6
Cattle Manure	0.5	44	440/10	Incorporation into soil	5.0	— / 7.82
DAP	—	—	10.5	Incorporation into soil	5.2	—
Group C — Jjagwe et al. [34]						
No fertilizer	—	—	—	—	4.02	7.6
Poultry Manure compost	0.7	31	60	Soil application, 120 g/plant	1.92	5.3 / 7.97
CM Vermicompost	0.7	31	248/8	Incorporation into soil	5.1	— / 6.43
NPK 250:150:125 (Urea + DAP+SOP)	—	—	10.5	Soil	7.5	— / 7.6
Group D — This Study (Kaduna, Nigeria, 2026)						
NPK + poultry manure (1:3)	0.48 ± 0.03	—	74/3.7	Soil, 14.85 ± 0.15 g/plant × 3	6.25 ± 1.80	6.4 / 7.9

Manure Type / Treatment	Bulk Density (g/cm³)	Weight of 50,000 cm³ (kg)	Applied bags/tonne	Application method	Yield (t ha⁻¹)	Soil/product pH
Group A — Mahmood et al. [32]						
NPK	1.10 ± 0.05	—	132/6.6	Soil, 26.4 ± 0.1 g/plant × 3	8.79 ± 2.19	6.4 / 7.5
IGOF	0.40 ± 0.01	—	52/2.6	Soil, 10.4 ± 0.15 g/plant × 3	10.27 ± 2.89	6.4 / 6.7
IGOF + poultry manure (1:3)	0.42 ± 0.02	—	54/2.7	Soil, 10.85 ± 0.13 g/plant × 3	7.54 ± 1.73	7.4 / 7.3

Table 3. Comparative fertilizer used to yield trial outcomes for maize — published literature and this study. Bulk density, material/soil pH and yield figures for This Study (Group E) are drawn from Table 2 above and Table 4 below (mean ± SD, n = 3). Soil/product pH is given as post-harvest soil pH (3 cm from roots) / material (pre-application) pH. "—" indicates a value not reported in the source or not yet calculated for this study.

This pH–yield trade-off is thrown into sharper relief when the present trial is set against comparable maize fertilization studies from the wider literature (Table 3). Fertilizer quantity applied (bags per hectare-equivalent) was the strongest single predictor of yield across both the literature comparators and the present trial, consistent with the classical dose-response relationship long established for maize nutrient management [18, 35]. In Mahmood *et al*. [32], yield rose from 1.19 t ha⁻¹ under an unfertilized control (12 bags) to 8.0–8.43 t ha⁻¹ once combined organic-plus-NPK inputs reached 80–84 bags, and Bekolo Ndongo *et al.* [33] reported the same monotonic pattern, from 2.8 t ha⁻¹ (28 bags, control) to 7.13 t ha⁻¹ (71 bags, poultry manure). The present trial reproduced this dose-response relationship exactly: yield rose in strict rank order with bag count across all four treatments — NPK + poultry manure (63 bags, 6.25 ± 1.80 t ha⁻¹), IGOF + poultry manure (75 bags, 7.54 ± 1.73 t ha⁻¹), NPK alone (88 bags, 8.79 ± 2.19 t ha⁻¹), and IGOF alone (102 bags, 10.27 ± 2.89 t ha⁻¹) — indicating that, within the range tested, the quantity of fertilizer material applied per unit area was a direct and consistent determinant of maize yield [36].

Soil pH shaped how much of that dose-driven yield potential was actually realized. Across all three literature datasets summarized in Table 3, the highest yields clustered at post-application pH values close to neutral, while treatments that pushed soil pH toward the alkaline extreme underperformed relative to their bag count alone. In Mahmood et al. [32], poultry manure alone raised soil pH to 8.03 yet produced only 2.0 t ha⁻¹, the lowest amended yield in that dataset, whereas treatments stabilizing near pH 7.6 (farmyard-, poultry-, and sheep-manure–NPK combinations) achieved 8.0–8.43 t ha⁻¹ at comparable bag counts. Jjagwe *et al.* [34] showed the same pattern: poultry-manure compost pushed pH to 7.97 but yielded only 1.92 t ha⁻¹, well below the 7.5 t ha⁻¹ achieved by NPK at the more moderate pH of 7.6. The present trial mirrors this relationship: NPK + poultry manure produced the largest pH shift (6.4 to 7.9, material pH) and the lowest yield in the trial despite a substantial dose (63 bags), while IGOF produced the smallest pH shift (6.4 to 6.7) and the highest yield at the largest dose (102 bags); NPK alone and IGOF + poultry manure, whose post-application pH values (7.5 and 7.3, respectively) fell between these two extremes, likewise produced intermediate yields (8.79 and 7.54 t ha⁻¹). This pattern is consistent with the well-established optimum pH range of approximately 6.0–7.0 for maize nutrient availability, above which phosphorus and micronutrients such as Fe, Mn, and Zn become progressively less soluble, capping yield response even when fertilizer dose is high [30, 37]. Together, these results indicate that fertilizer quantity set the upper bound on attainable maize yield in this trial, while the magnitude of the accompanying soil pH shift determined how much of that potential was realized — reinforcing the practical recommendation that the choice between IGOF alone and IGOF + poultry manure should be matched to whether a farmer's priority is maximum current-season yield or cumulative soil remediation.

3.3 Weed Emergence

Weeding was carried out on each plot only after the second fertilizer application, coinciding with an increase in rainfall. Thereafter, weeds were allowed to proliferate and grow independently through to harvest, with records and photographs taken before weed emergence and separately for the NPK and IGOF plots after the trial period. Heavier and faster weed colonization were observed under NPK than under IGOF. We interpret this as a consequence of the two fertilizers' release profiles: NPK is highly water-soluble and releases nitrogen rapidly into the soil solution, a flush of available nitrogen that opportunistic weed species are typically well placed to exploit quickly. IGOF's release, by contrast, was more gradual and tied to its more compact, organomineral matrix (Table 2, bulk density), which limited the pulse of freely leachable nutrient available to support weed germination and early growth — broadly consistent with evidence that rapid mineral-nitrogen release elevates reactive nitrogen availability in the wider soil-plant system relative to more slowly mineralizing organic sources [29]. Because weeding is itself a recurring labour and herbicide cost for smallholders, a fertilizer that structurally suppresses early weed pressure — as IGOF appears to do — offers a secondary, non-yield economic benefit not captured in the cost–benefit table (Table 7) alone.

3.4 Seed Yield Components, Plant Density, Grain Yield and Cob Development

Seed number and shelled seed weight per cob are shown for each of the three cob-size classes (big, medium, small) recorded under every fertilizer treatment, together with the pooled treatment mean ± standard deviation (SD; n = 3 size classes per treatment).

Data reconciliation note: the plant density and grain yield figures below have been updated from the original trial-plot density to the standard Nigerian hand-tillage planting density (2 plants per hole; 83,100 ± 15,329 plants ha^{-1}), as established in the Fertilizer Economy analysis (Section 3.6). This is the most agronomically representative basis and is applied uniformly here so that plant density and grain yield figures agree across every table in this report. Grain yield (t ha^{-1}) = mean seed weight cob^{-1} (g) × plant density (plants ha^{-1}) ÷ 1,000,000; SD propagated in quadrature from seed weight and density uncertainty.

Table 4

Seed yield components, plant density and grain yield of maize under organic and inorganic fertilizer sources. Seed weight and seed number values for Big/Medium/Small classes are single field measurements as recorded on the original data sheet. Mean ± SD rows pool the three size classes per treatment (n = 3). Plant density (83,100 ± 15,329 plants ha^{-1}) reflects the standard Nigerian hand-tillage convention (2 plants/hole) and is applied uniformly across treatments, superseding the original trial-plot density estimate. Grain yield (t ha^{-1}) = mean seed weight cob^{-1} (g) × plant density (plants ha^{-1}) ÷ 1,000,000. One-way ANOVA ($F_{3,8}$) tested differences among the four treatment means; ns = not significant at $p < 0.05$. Because plant density is constant across treatments, the grain-yield ANOVA is mathematically identical to the seed-weight ANOVA (F = 3.61, p = 0.065).

Treatment	Cob size class	Seed number cob^{-1}	Seed weight cob^{-1} (g)	Plant density (plants ha^{-1})	Grain yield (t ha^{-1}) ± SD
IGOF (organic fertilizer)	Big / Medium / Small	540 / 589 / 384	132.30 / 144.30 / 94.10	83,100 ± 15,329	10.27 ± 2.89
Mean ± SD	—	**504.33 ± 107.05**	**123.57 ± 26.21**		
NPK fertilizer	Big / Medium / Small	588 / 504 / 420	123.50 / 105.80 / 88.20	83,100 ± 15,329	8.79 ± 2.19
Mean ± SD	—	**504.00 ± 84.00**	**105.83 ± 17.65**		
IGOF + poultry manure (1:3)	Big / Medium / Small	512 / 410 / 406	104.90 / 84.10 / 83.20	83,100 ± 15,329	7.54 ± 1.73
Mean ± SD	—	**442.67 ± 60.08**	**90.73 ± 12.28**		
NPK + poultry manure (1:3)	Big / Medium / Small	448 / 420 / 288	87.40 / 81.90 / 56.20	83,100 ± 15,329	6.25 ± 1.80
Mean ± SD	—	**385.33 ± 85.45**	**75.17 ± 16.65**		
ANOVA ($F_{3,8}$) on treatment means	—	**F = 1.33, p = 0.331 ns**	**F = 3.61, p = 0.065 ns**	**(constant)**	**F = 3.61, p = 0.065 ns**

Mean seed number per cob ranged from 385.33 ± 85.45 (NPK + poultry manure) to 504.33 ± 107.05 (IGOF) and did not differ significantly among treatments ($F_{3,8}$ = 1.33, p = 0.331). Mean seed weight per cob ranged from 75.17 ± 16.65 g (NPK + poultry manure) to 123.57 ± 26.21 g (IGOF), approaching but not reaching significance at the 5% level ($F_{3,8}$ = 3.61, p = 0.065). Grain yield, calculated at the standard Nigerian hand-tillage plant density (83,100 ± 15,329 plants ha^{-1}, 2 plants per hole), ranged from 6.25 ± 1.80 t ha^{-1} (NPK + poultry manure) to 10.27 ± 2.89 t ha^{-1} (IGOF), also approaching but not reaching significance ($F_{3,8}$ = 3.61, p = 0.065), since yield is a direct linear function of seed weight at this fixed plant density. IGOF alone consistently gave the numerically highest seed number, seed weight and yield (Table 4), while NPK combined with poultry manure gave the lowest values on all three measures. These yield figures fall within the plausible range for field maize under smallholder hand-tillage practice (commonly 2–10 t ha^{-1}).

The yield advantage of IGOF was traceable down to the level of individual cobs and seeds (Table 4). Fresh seed weight differed only marginally between NPK and IGOF cobs at harvest (around 0.06%), but this gap widened substantially after oven-drying — to roughly 14.47% between IGOF and NPK, and 20.7% for NPK + poultry manure — indicating that the treatments differed as much in grain moisture content and dry-matter accumulation as in raw fresh weight. We attribute this widening post-drying difference to the additional nutrients, and the physical and biological soil changes, that IGOF's organic matrix contributes over the growing season, which plausibly support fuller grain fill and dry-matter deposition rather than simply heavier, wetter grain at harvest. This interpretation is consistent with evidence that maize and other food crops grown in compost-amended soils take up a distinctly different, and often

more complete, nutrient complement from the soil than crops grown under mineral fertilizer alone, with that compost-derived nutrient signature carried through into the harvested grain [38].

3.5 Grain Nutritional Quality: Proximate Composition and the Protein–Lipid Tilt

Proximate composition (moisture, ash, lipid, protein, fibre, carbohydrate) was determined in triplicate for maize grown under IGOF (organic; samples A–C) and NPK (inorganic; samples A–C) fertilization. For each parameter, the mean and standard deviation (SD) were calculated from the three replicates per treatment. Because this compares exactly two independent groups (IGOF vs NPK) with genuine replicate data (n = 3 each), an independent-samples t-test was used for each parameter — the appropriate and most robust test for a two-group comparison of means, equivalent to a one-way ANOVA with two levels. Levene's test confirmed equal variances between groups for every parameter ($p > 0.05$ in all cases), so Student's (pooled-variance) t-test was used throughout, with 4 degrees of freedom ($n_1 + n_2 - 2$).

Table 5
Proximate composition of maize grain grown under IGOF (organic) and NPK (inorganic) fertilization. Values are mean ± SD of triplicate determinations. Within a row, means followed by different superscript letters (a, b) differ significantly (independent t-test, $p < 0.05$); rows with no superscript letters did not differ significantly between treatments. Sig.: ns = not significant ($p \geq 0.05$); ** = p < 0.01;* ** = $p < 0.001$. df = degrees of freedom ($n_1 + n_2 - 2 = 4$). Levene's test showed no significant difference in variance between groups for any parameter (all $p > 0.05$), justifying use of the pooled-variance (Student's) t-test rather than Welch's correction.

Parameter	IGOF (organic) Mean ± SD, n = 3	NPK (inorganic) Mean ± SD, n = 3	t (df = 4)	p-value	Sig.
Moisture (%)	5.26 ± 0.04	5.17 ± 0.06	2.227	0.090	ns
Ash (%)	1.69 ± 0.04	1.75 ± 0.06	−1.576	0.190	ns
Lipid (%)	4.56 ± 0.03	4.38 ± 0.04	6.719	0.003	**
Protein (%)	16.10 ± 0.17	12.62 ± 0.45	12.649	< 0.001	***
Fibre (%)	2.19 ± 0.06	2.29 ± 0.05	−2.075	0.107	ns
Carbohydrate, CHO (%)	72.65 ± 0.22	75.55 ± 0.39	−11.165	< 0.001	***

Moisture, ash and fibre content did not differ significantly between IGOF- and NPK-fertilized maize ($p = 0.090$, 0.190 and 0.107 respectively), indicating these grain quality parameters were largely unaffected by fertilizer source in this trial. In contrast, lipid, protein and carbohydrate content differed significantly between the two fertilizer sources. IGOF-fertilized maize had significantly higher lipid content (4.56 ± 0.03% vs 4.38 ± 0.04%, $p = 0.003$) and markedly higher protein content (16.10 ± 0.17% vs 12.62 ± 0.45%, $p < 0.001$) than NPK-fertilized maize — a difference of roughly 3.5 percentage points in protein, which is agronomically and nutritionally substantial. Conversely, NPK-fertilized maize had significantly higher carbohydrate content (75.55 ± 0.39% vs 72.65 ± 0.22%, $p < 0.001$).

Maize is conventionally regarded chiefly as a carbohydrate staple, so this protein–lipid gain at the expense of carbohydrate share is a genuine compositional trade-off rather than an overall increase in every fraction, and the fact that moisture, ash and crude fibre did not differ significantly between the two sources indicates that the shift was concentrated specifically in the protein and lipid fractions rather than reflecting a broad change in grain composition. IGOF's biomass-derived matrix also carries trace elements — including Ca, Mg, Si, Fe and Zn — that are not part of conventional NPK formulations; work on maize and spinach grown on compost-amended soils has shown that such elements are measurably taken up from organic and compost-derived amendments and carried through into the

harvested crop [38], consistent with, though not direct proof of, the trace-element differences implied by IGOF's own material composition. Together with the yield result (Table 4), this protein–lipid tilt is arguably the single strongest quality argument for IGOF over NPK: it does not just produce more grain, it produces more nutritionally complete grain, which matters directly for food and nutrition security in the smallholder Nigerian households that consume much of what they grow.

3.6 Fertilizer Economy / Cost–Benefit Analysis and Smallholder Adoption

Typical Nigerian hand-tilled maize farms use a row × hole spacing of either 30 in × 11 in or 33 in × 13 in, with two maize seeds sown per hole. Hole density (holes ha⁻¹) was calculated from each spacing and averaged; plant density was then obtained by doubling hole density (2 plants per hole).

Table 6

Hole and plant density under typical Nigerian hand-tillage spacing conventions. Area/hole = row spacing (m) × hole spacing (m). Hole density = 10,000 m² ÷ area/hole. Plant density = hole density × 2 (two maize plants per hole). Mean ± SD is across the two spacing conventions (n = 2). Because the two plants sharing a hole are fertilized together (one application dose serves both), input/fertilizer cost is calculated using the hole density (41,550 ± 7,664 holes ha⁻¹) — not the doubled plant density. Revenue, however, depends on the total number of maize plants actually producing a cob, so grain yield and output/revenue are calculated using the doubled plant density (83,100 ± 15,329 plants ha⁻¹). Fertilizer quantities reflect three applications per season, and maize price is set at ₦15,000 per 50 kg (₦300,000 per tonne). Input cost ha⁻¹ = total quantity applied hole⁻¹ (kg) × hole density × cost kg⁻¹. Output/revenue ha⁻¹ = yield × ₦300,000. Net profit (loss) ha⁻¹ = output/revenue − input cost, with SD combined in quadrature from the underlying quantity, density, weight and yield uncertainties.

Spacing (row × hole)	Area/hole (m²)	Hole density (holes ha⁻¹)	Plant density, 2 plants/hole (plants ha⁻¹)
30 in × 11 in	0.213	46,970	93,940
33 in × 13 in	0.277	36,131	72,262
Mean ± SD	—	**41,550 ± 7,664**	**83,100 ± 15,329**

Table 7

Fertilizer economy / cost–benefit analysis under typical Nigerian hand-tillage planting density (2 plants per hole). ₦ = Nigerian naira. A negative net profit value indicates a net loss. Seed weight cob⁻¹ and grain yield values are the same reconciled figures used in Table 4.

Treatment	Total qty applied hole⁻¹, 3 applications (g) ± SD	Cost kg⁻¹ (₦)	Input cost ha⁻¹ (₦) ± SD	Seed weight cob⁻¹ (g) ± SD	Maize yield (t ha⁻¹) ± SD	Maize price 50 kg⁻¹ (₦)	Output/revenue ha⁻¹ (₦) ± SD	Net profit/(loss) ha⁻¹ (₦) ± SD
IGOF	31.20 ± 0.26	1,300	1,685,276 ± 311,188	123.57 ± 26.21	10.27 ± 2.89	15,000	3,080,615 ± 865,952	1,395,339 ± 920,169
NPK	79.20 ± 0.17	1,200	3,948,931 ± 728,480	105.83 ± 17.65	8.79 ± 2.19	15,000	2,638,355 ± 656,102	−1,310,576 ± 980,384
IGOF + poultry (1:3)	32.55 ± 0.23	550	743,852 ± 137,314	90.73 ± 12.28	7.54 ± 1.73	15,000	2,261,910 ± 517,504	1,518,057 ± 535,411
NPK + poultry (1:3)	44.55 ± 0.26	525	971,807 ± 179,352	75.17 ± 16.65	6.25 ± 1.80	15,000	1,873,997 ± 540,179	902,190 ± 569,175

Scaling the trial results up to typical Nigerian hand-tillage density (2 plants/hole, ≈ 83,100 plants ha⁻¹) and a maize price of ₦15,000/50 kg substantially improves the economics for three of the four treatments. IGOF + poultry manure

(1:3) gives the best return, with a net profit of ₦1,518,057 ± 535,411 ha⁻¹, helped by its low cost per kg (₦550) keeping input cost modest (₦743,852 ha⁻¹) against a healthy revenue of ₦2,261,910 ha⁻¹. IGOF alone is close behind at ₦1,395,339 ± 920,169 ha⁻¹ — its higher yield offsets its higher per-kg cost. NPK + poultry manure (1:3) is also solidly profitable, at ₦902,190 ± 569,175 ha⁻¹. NPK alone remains the outlier: even at the higher maize price, its very high application rate and cost per kg drive input cost to ₦3,948,931 ha⁻¹, well above its revenue of ₦2,638,355 ha⁻¹, producing a net loss of ₦1,310,576 ± 980,384 ha⁻¹. NPK applied alone is not economically viable at this rate and frequency, while all three organic/blended options are profitable — most strongly IGOF + poultry manure. It is also worth noting that these net-return figures carry very wide standard deviations relative to their means — for NPK alone, the ± 980,384 ha⁻¹ SD is around 75% of the ± 1,310,576 ha⁻¹ mean net loss, and the other treatments show comparably high relative variability. This reflects the small number of field replicates underlying each estimate and means the point estimates in Table 7 should be read as indicative of the direction and rough scale of the profitability gap between treatments rather than as precise figures; larger-sample replication would be needed to narrow these intervals.

Rising and volatile inorganic-fertilizer prices, driven by fossil-energy dependence, phosphate-rock scarcity and periodic geopolitical shocks, are steadily eroding the economics of NPK-based maize farming [19, 20], and Table 7 illustrates the practical consequence of that trend at the farm level. This pattern — organic and organomineral inputs outperforming straight inorganic fertilizer on net returns — mirrors findings from comparable maize trials elsewhere in Africa; Bekolo Ndongo *et al.* [33], for example, likewise reported that compost- and poultry-manure-based treatments delivered higher net returns than inorganic NPK in their own maize cost–benefit analysis. The wider stakes of this result are social as much as agronomic. Many Nigerian smallholders already carry agricultural loan debt and are increasingly reluctant to plant maize because of its steadily rising input cost, a pattern that, left unaddressed, threatens both household livelihoods and the broader economy and food security of the nation. A biomass-valorized organomineral fertilizer such as IGOF, used alone or blended with a modest proportion of poultry manure, offers smallholders a route back to profitable maize production: it subsidizes the input side of the farming budget relative to NPK, regenerates rather than depletes the soil resource base, and — as shown in Table 5 and Section 3.5 above — delivers a more nutritionally complete harvest for farming households that consume a share of what they grow.

4. Conclusion

This trial provides field-validated, quantitative evidence that a locally produced, waste-valorized organomineral fertilizer can outperform conventional NPK across four dimensions that matter jointly to smallholder maize production in Nigeria: soil health, yield, grain nutritional quality, and farm profitability. The clearest breakthrough is agronomic: IGOF blended with poultry manure (1:3) delivered the strongest correction of soil acidity recorded in this trial, raising soil pH by 1.30 units (from 6.4 to 7.7) where NPK alone left the underlying acidity essentially unaddressed — a result of particular importance given how widespread and costly untreated soil acidity remains across sub-Saharan Africa's cropland, and how inaccessible conventional lime-based correction is to most smallholders [31]. IGOF applied alone, meanwhile, delivered the highest grain yield (10.27 ± 2.89 t ha⁻¹) together with a significant nutritional tilt toward higher grain protein (16.10% vs 12.62%) and lipid (4.56% vs 4.38%) content relative to NPK — evidence that a shift to organomineral fertilization can improve not just how much maize a farm produces but how nutritious that maize is. These agronomic gains translated directly into economic ones: NPK applied alone was not commercially viable at typical Nigerian hand-tillage density, returning a net loss of over ₦1.3 million ha⁻¹ on fertilizer cost alone, whereas every IGOF-based option tested was profitable, with IGOF + poultry manure the strongest performer (₦1,518,057 ha⁻¹).

On this evidence, we recommend that Nigerian maize farmers on acidic soils prioritize IGOF blended with a modest proportion of poultry manure where soil remediation is the more pressing need, and IGOF applied alone where

maximizing the current season's yield is the priority, in preference to NPK applied without an organic complement. We further recommend that policy and extension programmes explore subsidizing or otherwise de-risking access to biomass-valorized organomineral fertilizers of this kind, given their demonstrated capacity to simultaneously ease farmers' input costs, regenerate degraded soils, and improve the nutritional quality of a staple national food crop. A further statistical caveat applies to the trial as reported: each of the four treatments was applied to two independently planted field plots (Section 2.4), and the "n = 3" used in the ANOVA and t-tests above corresponds to sub-samples (cobs, or laboratory replicates) pooled across that treatment's plot-pair rather than to plot-level means. With only two field plots per treatment, and with plot identity not modelled as a separate random-effect term in the analysis, the reported p-values likely still understate the true treatment-level uncertainty to some degree, distinct from the multi-site, multi-season generalizability question addressed below; expanding plot-level replication beyond two plots per treatment, and analyzing plot as an explicit random effect, should be treated as a priority alongside multi-season, multi-site testing. This trial was conducted at a single site over one growing season; confirming the durability of the pH correction, yield and nutritional gains reported here — and testing whether the IGOF-alone versus IGOF-plus-poultry-manure trade-off identified here holds across soils, seasons and locations — will require multi-season, multi-site replication, which we identify as the priority for future work.

Read against the United Nations Sustainable Development Goals, these results carry implications beyond a single trial. The soil-acidity correction delivered by IGOF + poultry manure is a direct, field-measured contribution to SDG 15 (Life on Land) and land degradation neutrality, addressing a soil constraint that conventional NPK left unresolved; the yield and nutritional (protein and lipid) gains from IGOF speak to SDG 2 (Zero Hunger) by improving both the quantity and quality of a staple food crop; the net profitability of every IGOF-based treatment, against NPK's outright loss, engages SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) for the smallholders who would adopt it; and the underlying transformation of agricultural residues that would otherwise be burned into a marketable soil input operationalizes SDG 12 (Responsible Consumption and Production) while avoiding the open-burning emissions that SDG 13 (Climate Action) targets. Scaling IGOF-type organomineral fertilizers therefore offers a concrete, locally produced route to advancing this cluster of goals simultaneously, rather than trading one off against another.

Abbreviations

The following abbreviations are used throughout this manuscript (alphabetized):

Abbreviation	Full Form
ABU	Ahmadu Bello University
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
CE	Circular Economy
CHO	Carbohydrate
CM	Cattle Manure
DAP	Diammonium Phosphate
df	Degrees of Freedom
FYM	Farm Yard Manure
GRA	Government Reserved Area
H_2SO_4	Sulfuric Acid
ha	Hectare
HCl	Hydrochloric Acid
HSD	Honestly Significant Difference (Tukey's post-hoc test)
IAR	Institute for Agricultural Research
IGOF	Instant Growth Organic Fertilizer
K_2O	Potassium Oxide (Potash)
MP-AES	Microwave Plasma–Atomic Emission Spectroscopy
Mt	Million Tonnes
NaOH	Sodium Hydroxide
NPK	Nitrogen, Phosphorus, Potassium (fertilizer)
ns	Not Significant
P_2O_5	Phosphorus Pentoxide (Phosphate)
PM	Poultry Manure
SD	Standard Deviation
SM	Sheep Manure
SOI	Sustainable Organic Innovations Limited
t ha^{-1}	Tonnes per Hectare
₦	Nigerian Naira

Declarations

Conflict of Interest

The author declares no conflict of interest.

Funding

This research received no external funding.

Ethics Declaration

Not applicable. This study did not involve human participants, human data, or animal subjects; it was a field agronomic trial on maize (Zea mays L.) and fertilizer products.

Plant Ethics Declaration

The maize (Zea mays L.) seeds used in this study were a common, non-endangered, locally cultivated mixed white/yellow variety, obtained through routine commercial purchase from a local seed retailer on Dikko Road, Tsuanin Kura GRA, Sabon Tasha, Kaduna North Local Government Area, Kaduna State, Nigeria (Supplementary Table S1), rather than collected from the wild. As a widely cultivated agricultural commodity with no protected, rare, or endangered status under Nigerian or international conservation law, no special collection permit, licence, or institutional/national approval was required beyond this standard commercial transaction. The collection and use of this plant material therefore complied with all applicable local and national guidelines for agricultural research in Nigeria, and no additional permissions were applicable.

Author Contributions

M. Gideon conceived and designed the study, conducted the field trial, performed the laboratory and statistical analyses, and wrote and approved the final manuscript.

Data Availability Statement

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Clinical trial number

Not applicable

Consent to publish declaration

Not applicable

Consent to participate declaration

Not applicable

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Figures

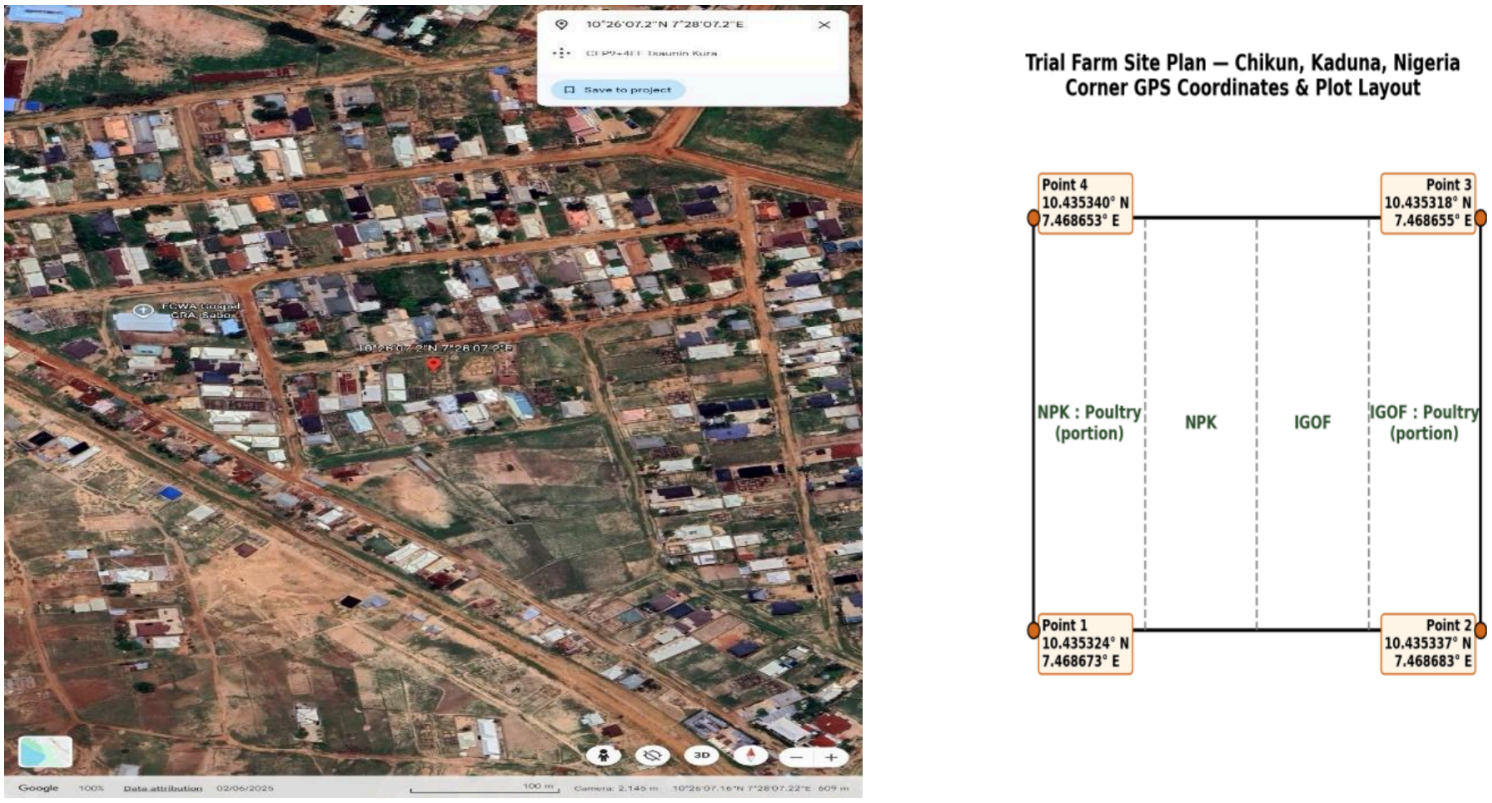


Figure 1: Schematic layout of the trial plot showing corner coordinates (Points 1–4) and the four planting portions.

Figure 1

See image above for figure legend



Figure 2. Prepared fertilizer materials before field application: (a) NPK + Poultry manure (1:3); (b) NPK blend (Golden 20:10:10 + Matrix 20:10:5, 1:1); (c) IGOF fertilizer; (d) IGOF + Poultry manure (1:3).

Figure 2

See image above for figure legend

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