International Journal of Applied Agricultural Sciences
2022; 8(6): 259-264
http://www.sciencepublishinggroup.com/j/ijaas
doi: 10.11648/j.ijaas.20220806.19
ISSN: 2469-7877 (Print); ISSN: 2469-7885 (Online)

Relative Performance of Coated Blends, Granular Blends and Compound Fertilizers on Maize Yield

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To cite this article:

Reda Ahmed, Quintar Genga, Mercy Ngunjiri, Leonardus Vergutz, John Wendt. Relative Performance of Coated Blends, Granular Blends and Compound Fertilizers on Maize Yield. *International Journal of Applied Agricultural Sciences*. Vol. 8, No. 6, 2022, pp. 259-264. doi: 10.11648/j.ijaas.20220806.19

Received: November 7, 2022; **Accepted**: November 23, 2022; **Published**: November 30, 2022

Abstract: Multi-nutrient fertilizers are becoming increasingly popular. Differences in relative crop response between blended and compound fertilizer forms have received little attention. This study was carried out to investigate the relative performance of a compound fertilizer, a blend formulated with coated micronutrients (zinc and boron), and a blend formulated with granular micronutrients. *Yara Mila^{TM} Power^{TM}* compound fertilizer was used as the nutrient reference fertilizer, and two blends were formulated to apply the same amounts of nutrients per hectare. Both full and half rates of each fertilizer were applied. A randomized complete block design (RCBD) with four replications was employed at two sites in Bungoma county, Kenya using maize as a test crop. Ear-leaf analyses showed non-significant differences for most nutrients in most treatments within sites, with leaf N, K, S, B and Zn deficiency evident at both sites. Leaf deficiencies of Zn and B suggest that rates may not have been adequate for optimal production. Site 2 (pH 4.52) showed substantially lower ear-leaf nutrient concentrations compared with Site 1 (pH 5.14), particularly for Mg and Ca, which were also deficient in initial soil analysis at both sites. At Site 1, no significant differences were noted between the micronutrient coated blend, granular blend and compound, and yields were greatest at the full rate of fertilizer. At Site 2, the micronutrient coated blend gave significantly greater yields than the granular blend and the compound, and yields were not affected by fertilizer rate. We conclude that micronutrient-coated blends can be as effective or more effective than fertilizer compounds containing the same nutrient concentrations.

Keywords: Compound Fertilizers, Coated Blend, Granular Blend, Micronutrients, Acid Soil, Maize Yield

1. Introduction

Inorganic fertilizers are essential component of sustainable soil fertility management [1]. They are available commercially in many physical and chemical forms. Each form has its own uses and limitations, which provide the basis for selecting the best fertilizer for specific crops or locations [2]. These forms can be broadly categorized as straight fertilizers, compound fertilizers, and blended fertilizers.

Straight fertilizers are defined by Gowariker, V. [3] as "fertilizers containing only one primary plant nutrient. Urea, ammonium nitrate, superphosphate and muriate of potash, for instance, are straights." In some parts of the world, the term single fertilizer is used instead. Compound fertilizers, also called complex, composite or multi-nutrient fertilizers, are defined by Finch, H. [4] as "homogeneous products containing two or more of the primary plant nutrients produced through chemical reactions in a factory. These nutrients are nitrogen, phosphorus, and potassium. A compound fertilizer is free-flowing and can contain micronutrients." A blended fertilizer, also called a blend, a mixed fertilizer, or a bulk blended fertilizer, is defined by Gowariker, V. [3] as "a multi-nutrient fertilizer made by dry blending several fertilizer materials of the same particle size range with no chemical reaction among them. Blended fertilizers have at least two of the essential plant nutrients N, P and K". This mixing can be done between two or more straight fertilizers, compound fertilizers or a combination of straight and compound fertilizers and may include secondary and/or micronutrients. Approximately 75% of all fertilizers now used are compounds or blends [4].

Compound granules have very similar shape, size, and density, and all the nutrients are contained in every fertilizer granule, which results in easier handling, more effective spreading and better nutrient distribution when applied to the soil. Blends may be less easy to handle and spread due to variations in granule shape, size, and density. However, they are often less expensive than compounds per unit of nutrient applied. Moreover, they can be produced in small, customized batches to meet specific farmer requirements or to address deficiencies prevalent in a region for priority crops, whereas compounds must be produced in large batch runs and are not as customizable.

When small percentages of micronutrient materials are to be added to granular fertilizers, they may be added as granules or as powdered coatings or liquid suspensions onto the surfaces of fertilizer granules. When coated onto granular fertilizers, micronutrients are evenly distributed, whereas when micronutrients are applied in granular forms in blends, they are relatively poorly distributed, as they comprise a small portion of the fertilizer granules and thus may be spatially distant when applied. This poor distribution results in the need to increase micronutrient rates to get optimal response. Several ways of coating micronutrients onto granular fertilizers exist, including 1) spraying a liquid micronutrient suspension onto blends: 2) introducing dry micronutrient powders formulated to adhere to blended granules into the blending process; and 3) attaching micronutrient powders to granular blends using a liquid adhesive product. Santos, G. A. et al. [5] reported a two-fold increase in maize dry matter from micronutrient-coated blend of NPK compared with a blended fertilizer having the same formulation. They recommended coating only 0.1% and 0.3% of B and Zn, respectively, using a vegetative oil as an adhesive product, which was equivalent to the application of 0.15 kg B ha^{-1} and 0.45 kg Zn ha^{-1} at an application rate of 150 kg ha^{-1}.

Maize (*Zea mays*) is the most important staple food crop in western Kenya, contributing some 40-50% of calories to the diet [6]. Its yield in this area is only 0.8 – 1.4 t ha^{-1}, while the actual potential is four-fold, mainly due to declining soil fertility [7] and Striga (*Striga hermonthica*) weeds [8] As various plant nutrient deficiencies limit crop yields in Sub-Saharan Africa (SSA), fertilizer application to the soil is a regular field management practice, with significant positive influence on plant health, biomass, and both quality and quantity of harvested products [9, 10].

Little information is available on whether the form of the fertilizer (compound, coated blend, or granular blend) affects yield response for similar nutrient applications. As multi-nutrient fertilizers become increasingly available, it is important to know whether particular forms give superior crop response. Thus, this study was undertaken to compare the effect of compound vs. blended (coated and granular) fertilizers of the same composition on maize yield and yield attributes in Western Kenya. It was hypothesized that 1) coated blends will outperform granular blends in terms of crop yield and nutrient concentration, due to better distribution of micronutrients in coated blends; and, 2) compound fertilizers will show the best performance on maize yield and nutrient concentration owing to the most uniform nutrient distribution of both micro and macronutrients compared to blended fertilizers.

2. Materials and Methods

2.1. Site Description

This study was carried out on two sites in Bungoma county, western Kenya during the long rainy season beginning in March 2020. Western Kenya's climate is tropical sub-humid with 900–2200 mm rainfall per year [11]. Bungoma county soils are primarily Acrisols and Cambisols with overlying petroplinthite subtypes [12, 13]. Annual precipitation has a bimodal distribution, consisting of an initial long to medium season from March to July, which precedes a relatively shorter season from September to December. The maize growing period ranges from 100 to 150 days [13-15], with the long season of precipitation being more suitable for its growth. With an average potential yield ranging from 5 to 10 t ha^{-1} [15], western Kenya is considered to be a medium potential area for maize production.

2.2. Experimental Design

The experiment employed a randomized complete block design (RCBD) [16] and consisted of a no-fertilizer control, two rates of the compound, two rates of the micronutrient-coated blend, two rates of the blend with granular micronutrients, and one treatment using a fertilizer blend without the micronutrients B and Zn. Four replications were used at each site. Nutrients applied in the treatments are shown in detail in Table 1. *Yara Mila Power*™ compound fertilizer (13:24:12: 4S:1MgO:0.2Fe:0.1Zn) was used as the nutrient reference fertilizer, and subsequent blends and application rates matched the nutrients applied in this compound in kg ha^{-1}. This fertilizer was coated with Solubor and Zn oxysulfate to achieve 0.15% B and 0.3% Zn, sufficient to address deficiencies of these nutrients when applied at approximately 200 kg ha^{-1}.

The fertilizers used to make the blended treatments were urea (46% N), NPS (19-38- 0 +7S), DAP (18% N, 46% P_2O_5), KCl (60% K_2O), MagPrill™ (9.5% Mg, 25% Ca), powdered Zn oxide (80% Zn), granular and powdered zinc sulfate monohydrate ($ZnSO_4*H_2O$, 35% Zn), Solubor® powder (20.9% B), Granubor™ (14.7% B), and iron sulfate heptahydrate ($FeSO_4*7H_2O$) powder (20% Fe). A commercial adhesive product (Pearl Forti, manufactured by Experse, South Africa), was used to bind the micronutrient powders to the granular fertilizers.

The recommended rate for the *Yara Mila Power*™ compound fertilizer is 200 kg ha^{-1}. We maintained this rate for the "full" fertilizer rate, plus 3 kg ha^{-1} which represented the Zn and B supplemented into this fertilizer. The half rate was half of this. All other fertilizers were applied at rates to supply the same nutrients in the "full" and "half" treatments represented in the Yara compound.

All fertilizers were applied pre-planting at a depth of 10 cm in a band. Urea was applied as a top-dress fertilizer some 6 weeks after planting, 10 cm to the side of the plants and 10 cm deep, at a rate of 185 kg ha^{-1}. Details on basal nutrient application rates in each treatment are shown in Table 1.

Table 1. *Nutrients supplied for each treatment in the trial in the basal formulation.*

Fertilizer type	Rate	N	P_2O_5	K_2O	S	MgO	Zn	B	Fe
		------------------------Nutrient application, kg ha^{-1}----------------------							
Compound	Full	26	48	24	8.1	2	0.6	0.3	0.4
Coated blend	Full	26	48	24	8.1	2	0.6	0.3	0.4
Granular blend	Full	26	48	24	8.3	2	0.6	0.3	0.4
Compound	Half	13	24	12	4.1	1	0.3	0.15	0.2
Coated blend	Half	13	24	12	4.1	1	0.3	0.15	0.2
Granular blend	Half	13	24	12	4.0	1	0.3	0.15	0.2
Blend -Zn, -B	Full	26	48	24	8.0	2	0	0	0.4
No fertilizer	0	0	0	0	0.0	0	0	0	0

Plots consisted of 4 rows of maize spaced at 0.75 m of 5 m length. Maize seeds were planted every 0.25 m along the row at two seeds per hole and later thinned out to one per hole after emergence, giving a density of 5.33 plants m^{-2}. Seeds were placed at 5 cm depth, 5 cm above banded fertilizer, and covered with soil on March 24th at Site 1 and March 25th at Site 2. Six weeks later, seedlings were top-dressed with urea when signs of N deficiencies started to appear.

To ensure weed-free plots, weeding using a hand hoe was done three times: two weeks after sowing, 4 weeks after sowing followed by topdressing of urea, and 13 weeks after sowing, just before tasseling. Orthene pesticide (100 g in 40 liters of water per single spray) was used to control fall army worm and was applied three times as required at both sites.

2.3. Soil Sampling and Soil Analysis

Representative composite soil samples (0-20 cm) were collected from each experimental site using augers before planting. Total of ten (10) cores were collected from each site, thoroughly mixed and then sent to Crop Nutrition Laboratory Services (CNLS) for analysis for soil pH, electrical conductivity (EC), soil organic matter, total N, and Mehlich-3 P, K, S, Mg, Zn, B and Fe.

2.4. Plant Analysis and Data Collection

At early silking stage, ten ear leaves were randomly collected from each plot. These samples were rinsed of dust and other contaminants, air-dried in a greenhouse, and sent to CNLS for nutrient concentration determination. Total N was determined from a Kjeldahl digest employing sulfuric acid, hydrogen peroxide and selenium, followed by addition of sodium hydroxide, distillation, and titration of the distillate with boric acid. All other elements were determined from a microwave digest employing nitric and hydrochloric acids by inductively coupled plasma spectroscopy. At harvest, cobs of the two middle rows were taken from each plot. Actual grain moisture content was determined, and yield results adjusted to 13% moisture content.

2.5. Data Analysis

Analysis of variance of data at each site was run using R programming language, and means were compared using the Duncan's Least Significant Difference (LSD) test at 5% level of probability. For yield, sites were initially analyzed comparing all 8 treatments, then further analyzed using the 6 treatments in a factorial arrangement (3 fertilizer types x 2 fertilizer rates).

3. Results and Discussion

3.1. Soil Analysis

Table 2 shows the site characteristics and pre-planting soil analysis for the two sites. Soils were acidic, particularly at Site 2 (pH = 4.5). Both sites were low in N, K, Ca, Mg, B and CEC. Sulfur, Cu, Zn and OM were found sufficient at Site 1 but deficient at Site 2. Phosphorus was sufficient at Site 2 but deficient at Site 1.

Table 2. *Site descriptions and initial soil analysis for the two trial sites.*

Site no.	GPS Coordinates		County	Sub-	Ward	Soil color	Slope
	Latitude	Longitude		County			
1	0.76426	34.7098	Bungoma	Bituyu	Kimilili	red	level
2	0.49639	34.4442	Bungoma	Bumula	Khasoko	red	level

Site no.	pH	EC	Total N	Organic matter	C/N	CEC	Sand	Silt	Clay
	H2O	µS cm^{-1}	%	%	ratio	cmolc kg^{-1}	%	%	%
1	5.14	16.9	0.1	2.62	15.2	5.34	49	10	41
2	4.52	22.5	0.063	1.35	12.5	3.62	85	8	7

Site no.	P	K	S	Ca	Mg	B	Zn	Fe	Mn	Cu
	---------------------Mehlich-3 extractable, ppm-----------------------------------									
1	2.1	63	11.2	401	72	0.14	3.9	97	95	2.6
2	68.7	40	8.8	186	30	0.32	1.2	114	52	0.88

3.2. Ear-leaf Nutrient Analysis

Table 3 shows ear-leaf nutrient analyses and sufficiency criteria for key nutrients in maize according to plant analysis with standardized scores (PASS) [17, 18]. Plant ear-leaf samples were deficient in N, K, S, B and Zn and sufficient in Ca, Fe, Mn and Cu were sufficient in all the treatments at both sites. Phosphorus was sufficient at Site 2 and deficient at Site 1, while Mg was sufficient in ear leaves at Site 1 but deficient at Site 2, reflecting the site soil analyses. Site 1, having a greater pH, SOM concentration and CEC, had higher levels of Ca, Mg, S, and all micronutrients except for Fe. These soil properties may have played a role in increased availability of micronutrients through chelation, thus minimizing nutrient loss and/or immobilization [19]. Most nutrient concentrations were similar between treatments within each site, with lower levels of some nutrients being most commonly evident in non-fertilized controls.

Boron variations within either site was negligible between treatments, and B was deficient in treatments with or without B. Santos, G. A. et al. [5] found that B concentrations in maize leaves were statistically similar from both coated blends and granular blends at recommended rates (2.4 kg B ha^{-1}). Likewise, Baxter et al. [19] reported that B coated onto fertilizers did not exhibit a significant increase in plant leaf B but observed an increase in plant B when the B application rate was escalated from 0.1 to 2.4 kg B ha^{-1}. All Zn treatments showed ear-leaf Zn concentrations below sufficiency levels. Zinc concentrations were not affected by treatment, except for the control treatment at Site 1. The low Zn and B concentrations suggest that greater rates may have resulted in more optimal yields.

***Table 3.** Duncan's analysis for ear-leaf samples at early silking (~50% tasseling).*

Treatment	Rate	N	P	K	S	Ca	Mg	B	Zn	Fe	Fe/Zn	Mn	Cu
		%	%	%	%	%	%	ppm	ppm	ppm	Ratio	ppm	ppm
		Site 1											
Compound	Full	2.38 a*	0.22 a	0.84 ab	0.15 ab	0.75 a	0.38 a	2.9 a	14.0 ab	167 a	12	170 abcd	10.0 a
Coated blend	Full	2.49 a	0.23 a	1.01 a	0.16 a	0.77 a	0.38 a	2.9 a	14.2 ab	166 a	12	153 cd	10.5 a
Granular blend	Full	2.61 a	0.22 a	0.80 b	0.16 a	0.95 a	0.44 a	2.8 a	15.8 a	174 a	11	189 ab	10.7 a
Compound	Half	2.61 a	0.22 a	0.71 b	0.15 ab	0.89 a	0.45 a	2.7 a	13.3 ab	165 a	12	182 abc	10.4 a
Coated blend	Half	2.66 a	0.24 a	0.83 ab	0.16 a	0.89 a	0.44 a	2.6 a	14.8 ab	173 a	12	175 abc	10.9 a
Granular blend	Half	2.53 a	0.23 a	0.79 b	0.16 a	0.90 a	0.42 a	2.7 a	15.7 a	160 a	10	160 bcd	10.8 a
Bland -Zn, B	Full	2.49 a	0.23 a	0.84 ab	0.16 a	0.85 a	0.43 a	2.9 a	15.8 a	170 a	11	199 a	9.6 a
Control	Zero	2.28 a	0.20 b	0.88 ab	0.13 b	0.83 a	0.38 a	2.8 a	12.8 b	190 a	15	138 d	7.4 a
		Site 2											
Compound	Full	2.22 ab	0.34 ab	1.36 a	0.12 a	0.39 bc	0.09 a	2.3 a	11.1 a	183 a	16	100 bc	8.0 a
Coated blend	Full	2.28 ab	0.31 ab	1.18 a	0.12 a	0.55 a	0.12 a	2.2 a	12.2 a	202 a	17	132 ab	7.9 a
Granular blend	Full	2.28 ab	0.29 b	1.32 a	0.11 a	0.48 ab	0.10 a	2.3 a	11.8 a	186 a	16	116 b	7.0 a
Compound	Half	2.44 a	0.31 ab	1.18 a	0.11 a	0.45 abc	0.11 a	1.9 a	11. a	171 a	15	110 b	7.7 a
Coated blend	Half	2.44 a	0.29 ab	1.18 a	0.12 a	0.46 abc	0.10 a	2.0 a	11.0 a	175 a	16	159 a	7.8 a
Granular blend	Half	2.35 a	0.33 ab	1.20 a	0.11 a	0.41 bc	0.09 a	2.0 a	11.23 a	178 a	16	125 b	8.0 a
Coated -Zn, B	Full	2.15 ab	0.33 ab	1.27 a	0.11 a	0.42 abc	0.09 a	2.1 a	10.8 a	173 a	16	107 b	7.1 a
Control	Zero	1.87 b	0.36 a	1.43 a	0.12 a	0.33 c	0.08 a	2.1 a	11.1 a	179 a	16	70 c	6.1 a
Sufficiency range		2.75-3.75	0.25-0.5	1.75-2.75	0.18-0.4	0.3-0.6	0.16-0.4	5-40	19-75	50-250	<7	19-75	3-15

*Means followed by the same letter are not significantly different at P≤0.05.

3.3. Grain Yield

Figure 1 shows yields for the 8 treatments at both sites. At Site 1, the only significant difference between treatments was the non-fertilized control. At Site 2, in addition to the control, a significant difference was observed between the coated fertilizer formulations at either rate and the granular blend with Zn and B at the lower rate.

A further factorial analysis of the fertilizer type (granular blend, coated blend, and compound) by rate (full or half) yielded different results for the two sites (Table 4). At Site 2, the fertilizer type was significant, with the coated blend yielding the highest, the granular blend yielding the lowest, and the compound intermediate. Fertilizer rate had no effect at Site 2. At Site 1, while the average trend in fertilizer type was observed amongst the average, fertilizer type was insignificant at P<0.05 due to high within-site variability. Rate was significant at Site 1, with the full rate resulting in significantly greater yields.

Despite the significant differences in fertilizer types, the granular blend without Zn and B did not yield significantly less than any fertilizer type with Zn and B at either site. The plant analytical data (Table 3) indicates that Zn and B were still deficient in treatments receiving those elements and suggests that the application rates of Zn and B (0.6 and 0.3 kg ha^{-1}, respectively) may have been inadequate to address the full crop demand.

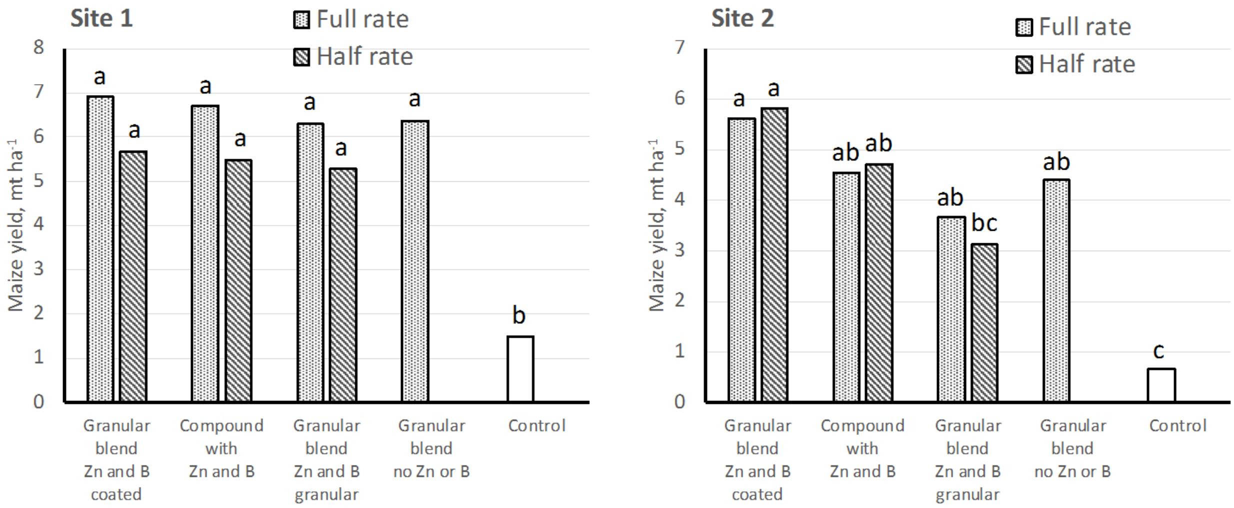

Figure 1. *Effects of fertilizer type and rate on grain yield. Means followed by the same letter are not significantly different at P≤0.05.*

Table 4. *ANOVA for the effect of fertilizer type and rate on maize yield.*

	Fertilizer type	Maize yield mt ha^{-1}		Fertilizer rate	Maize yield mt ha^{-1}	
Site 1	Coated blend	6.20	a*	Full	6.64	a
	Compound	6.19	a	Half	5.48	b
	Granular blend	5.79	a			
Site 2	Coated blend	5.71	a	Full	4.61	a
	Compound	4.63	b	Half	4.55	a
	Granular blend	3.40	c			

* Means followed by the same letter are not significantly different at P≤0.05.

This fact notwithstanding, the coated blend significantly outyielded the granular blend at Site 2, as well as the compound. It is unsurprising that the coated blend would be expected outyield the granular blend, as granular micronutrients are poorly distributed in a blend, making root interception less likely. We hypothesized that the compound would give the greatest yield due to better distribution of all nutrients, which are contained in every granule of the compound. This even distribution, however, may also result in more precipitation of insoluble compounds such as Zn borates, Zn phosphates, and Zn ammonium phosphates in a compound, and may be responsible for the lower yields using the compound fertilizer at Site 2.

Shivay, Y. S. et al. [20] reported that only 2.4 kg ha^{-1} of Zn as Zn sulfate, when coated onto urea, resulted in similar rice grain and stover yields as 25 kg Zn of Zn sulfate granules applied simultaneously with urea, while simultaneously resulting in greater Zn concentration in rice grains. Furthermore, Ruffo, M. et al. [21] found that fertilizing maize with a compound fertilizer containing 2.24 kg Zn ha^{-1} gave the same yield as a granular blend containing 11.2 kg Zn ha^{-1}. Thus, whether through compounding or coating, better Zn distribution was able to achieve better Zn efficiency compared to granular Zn sources, similar to Site 2 in our trial.

4. Conclusion

Plant analyses indicate that Zn and B were deficient both sites. However, application of Zn and B at 0.6 kg Zn ha^{-1} and 0.3 kg B ha^{-1} did not substantially improve ear leaf concentrations of either nutrient, suggesting that the Zn and B rates chosen were sub-optimal. There was no indication of Zn and B response at Site 1. At Site 2, yields were significantly different for the 3 fertilizer types, in the order of coated blends > compounds > granular blends. This order is indicative of Zn and B response, as the only difference between coated and granular blends is Zn and B distribution, which is better in coated blends and hence the cause of the differential response. The yield difference averaged 2.3 t ha^{-1}, showing that micronutrient distribution is critical in blends.

The hypothesis that compounds, having even distribution of all nutrients in every granule, will result in the greatest yield, was not supported by this experiment. Coated blends gave either greater yields or statistically equivalent yields as fertilizer compounds. We hypothesize that this may be due to chemical reactions that can occur between nutrients in compounds, thus reducing the solubility of some nutrients.

The authors, thus, recommend more investigations in this topic to further address the performance of different fertilizer compositions under various conditions.

Declaration of Interest Statement

The authors declare that there is no conflict of interest.

Acknowledgements

The authors would like to thank OCP Africa for funding this work and extend my gratitude to IFDC-Kenya for their sponsorship.

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