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Evaluating Added Benefits from Combined Cattle Manure and Fertilizer Application in a Maize Cropping System

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Abstract: A field experiment was conducted at Kpongu in the Upper West region of Ghana to determine the added benefits in grain yield of maize derived from the concurrent use of manure and mineral fertilizer, and their cost effectiveness. Factorial combinations of cattle manure and mineral fertilizer each at 0, 50 and 100% of their recommended rates were evaluated in both the field and the laboratory studies. The treatments were applied in a randomized complete block design with three replications on the field. The same treatments were applied in the incubation study in a completely randomized design. The use of 100% NPK (Nitrogen, Phosphorus, Potassium) + 5 t manure gave the highest grain yield of 4,678 kg·ha^{-1}. Synergistic interactions resulting in added benefits in grain yield were observed in all the combined nutrient inputs except 50% NPK + 2.5 t manure which accrued an added disadvantage of 44 kg·ha^{-1}. Economic analysis proved that 100% NPK + 2.5 t manure and 50% NPK + 5 t manure were the most economically viable combined treatments in terms of grain yield. Based on the results from this study, resource poor farmers in the Upper West region of Ghana may reduce mineral fertilizer recommended rates by 50% and supplement it with 5 t quality (N >2.5%) cattle manure without compromising yield and profit.

Key words: Synergistic interaction, yield, value cost ratio.

1. Introduction

The combined use of organic and inorganic nutrient sources is an integrated nutrient management option acclaimed to be capable of replenishing the declining soil fertility in sub-Saharan Africa [1] due to synergistic interaction [2] that may exist between these nutrient sources. This interaction may lead to the attainment of extra crop yields compared to the sum of yields from individual applications. Research done by Palm, C. A. et al. [2] proposed the terms added benefits for the extra yield obtained from combining organic and inorganic nutrient sources as a result of synergistic interaction between the two. Added disadvantage was also used to describe a decline in yield from combined application compared to the sum of yields from individual applications [2], a condition resulting from an antagonistic interaction between the two nutrient inputs. When Vanlauwe, B. et al. [3] applied 90 kg·ha^{-1} N, farmer available organic resources and an equal combination of both, all with 30 kg·ha^{-1} basal P, it was observed that maize yield from combined applications was higher for all replications than sole applications. This yielded an added benefit of 514 kg·ha^{-1} maize grain worth $136 and reduced input purchase by $56 and Vanlauwe, B. et al. [3] attributed the extra yield obtained from combined application to an improvement in synchrony between crop nutrient demand and soil nutrient release. In another study, Vanlauwe, B., Wendt, J. and Diels, J. [4] attributed extra yield obtained to the ability of manure to improve soil quality properties such as

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CEC (Cation Exchange Capacity), pH and water holding for effective utilization of mineral fertilizer nutrients. Giller, K. E. [5] also proposed priming of soil nutrients when manure and mineral fertilizer are combined as the reason for the added yield benefits obtained from combined application of different nutrient inputs. Many studies conducted on combined manure and mineral fertilizer use reported improvement in yield [6, 7] without quantifying the added benefits due to synergy. Therefore research geared towards an insight into quantifying the added benefits due to synergy is required. Thus the objectives of this study were to (1) estimate the effect of combined application of cattle manure and mineral fertilizers on yield of maize; (2) quantify the added benefits in maize yield from combined application (3) assess the cost effectiveness of nutrient inputs to the soil.

2. Materials and Methods

2.1 Characteristics of Study Site Soil

The field experiment was conducted at Kpongu in the Upper West region of Ghana (latitude 09°57'48.6'' N and longitude 002°30'31.4'' W at an elevation of 286 m above sea level). The soil of the site is mainly savannah ochrosols and groundwater laterites [8] with a sandy texture. The area receives a uni-modal rainfall pattern of about 1,000 mm/annum.

Soil of the experimental site was inherently low in soil nutrients, organic matter and moderately acidic (Table 1). It was high in potassium (K) probably due to rampant bush burning in the study area. Similarly, soil used for the incubation study was inherently low in nutrients with extremely low microbial biomass carbon probably due to the site's poor history of manure application.

2.2 Characteristics of Manure

Manure samples (500 kg) were taken from eight different cattle kraals and mixed thoroughly to form a composite.

According to the quality rating by Bationo, A. et al. [9], the manure was of a good quality considering its low C: N ratio and high N content (N > 2.5%) (Table 2)

Table 1 Initial physical and biochemical properties of soil at the study site.

Property	Field study
Clay (%)	3.00
Silt (%)	4.04
Sand (%)	92.96
Soil moisture (%)	5.15
Bulk density ($g \cdot cm^{-3}$)	1.50
Soil pH (1:1 H_2O)	5.75
Organic matter (%)	1.05
Total N (%)	0.06
Available P ($mg \cdot kg^{-1}$)	9.97
Exchangeable K ($cmol_c \cdot kg^{-1}$)	0.85
Exchangeable Ca ($cmol_c \cdot kg^{-1}$)	1.60
Exchangeable Mg ($cmol_c \cdot kg^{-1}$)	0.58

Table 2 Chemical properties of cattle manure.

Parameter	Carbon (%)	Total N (%)	Total P (%)	Total K (%)	*DMC (%)	C: N
Value	23.65	2.76	0.41	0.59	51.73	8.58

* DMC-Dry Matter Content.

2.3 Land Preparation, Experimental Design and Treatments

The land was slashed, ploughed and harrowed to a fine tilth and laid out in a randomized complete block design with three replications in a factorial fashion. Plot sizes were 4 m × 3 m with 1 m alley between and within plots. The treatments applied included three levels of mineral fertilizer (0, 50 and 100% of 60: 40: 40 kg·ha^{-1} NPK (Nitrogen, Phosphorus, Potassium) recommended rate) and three levels of cattle manure (0, 2.5 and 5 t/ha).

2.4 Laboratory Analysis of Manure and Soil Samples

Twenty seven core soil samples were taken from the experimental site before planting (one sample per plot) at 15 cm depth at field capacity and bulked to form a composite. It was air-dried and sieved through a 2 mm wire mesh. Soil texture was determined using particle size analysis [10]. Soil pH was determined with distilled water in a 1: 1 ratio [11]. Organic carbon was determined by the wet oxidation method [12]. Soil total nitrogen was analyzed using Kjeldahl digestion method. Available phosphorus was also determined with Bray P 1 method [13]. Exchangeable K was determined by the flame photometry method.

Five kg sub-samples were air-dried for five days, milled with Perten's laboratory mill (3310) and analyzed for total N (Kjeldahl digestion), phosphorus (Bray P-1), potassium (Ammonium acetate flame photometry method) and carbon (Walkley and Black, wet oxidation method). The dry matter content of the manure was determined.

2.5 Planting and Crop Management

Cattle manure was broadcasted on respective plots and mixed with a hoe to about 10 cm depth 2 weeks before planting to allow some time for decomposition. The test crop, maize (Akposoe) was planted 2 seeds per hill at a spacing of 80 cm × 40 cm. Refilling was done a WAP (Week After Planting). Weeding was done when necessary. NPK was applied as urea (N), murate of potash (K_2O) and triple super-phosphates (P_2O_5) at 2 WAP. Urea was split applied at 2 WAP and the other half applied at 5 WAP.

2.6 Data Collection

Initial soil analysis was done to determine the physico-chemical properties of the soil. Grain yield was determined after physiological maturity of the maize. Farm gate and selling prices of maize were determined from wholesale market at Wa in the Upper West region of Ghana.

2.7 Statistical Analysis

The data was subjected to analysis of variance using GENSTAT (General Statistics) version 12 and significant means separated using LSD (Least Significant Difference) at 5%. PCA (Principal Component Analysis) was used to determine the relative contribution of the studied mechanisms (improved nutrient synchrony, priming effect and general fertility improvement) to synergy.

2.8 Calculations

2.8.1 Added Benefit

$$Added\ benefit\ (AB) = Ycomb - (Yfert - Ycon - Yom - Ycon - Ycon \text{ [4]}$$

where Ycon means grain yields in the control treatment, Yfert means grain yields in the treatments with sole application of fertilizer, Yom means grain yields in the treatment with sole organic matter application and Ycomb means grain yields in the treatments with both mineral fertilizer and organic matter input.

2.8.2 Value Cost Ratio

The cost effectiveness of the applied nutrient inputs were determined using VCR (Value Cost Ratio)

$$VCR = ((Y - Yc))/X \text{ [14]}$$

where Y = the monetary value of the crop in intervention (treated) plots, Yc = monetary value of the crop harvested in control plots, and X= monetary cost of inputs (seeds and fertilizers) and labour.

3. Results and Discussion

3.1 Effect of Manure and Mineral Fertilizer Application on Maize Grain Yield

Each increased level of manure and mineral fertilizer significantly increased ($p < 0.05$) grain yield (Table 3) probably due to the supply of more nutrients with increasing rates of application, which led to a consequent increase in growth and yield [6]. The application of 60: 40: 40 kg·ha^{-1} NPK significantly ($p < 0.05$) produced the highest grain yield (3,618 kg·ha^{-1}) with an excess (1,116 kg·ha^{-1}) over 30: 20: 20 kg·ha^{-1} NPK and 2,363 kg over the control. Sole application of 5 t manure significantly produced the highest grain yield (3,451 kg·ha^{-1}) followed by 2.5 t manure (2,515 kg·ha^{-1}) while 0 t manure gave the least (1,400 kg·ha^{-1}).

The observation that increasing rates of manure and mineral fertilizer applied concurrently increased grain yield (Fig. 1) with 60: 40: 40 kg·ha^{-1} NPK + 5 t manure producing the highest grain yield may be due to the availability of more nutrients supplied in balanced proportions [19]. The fact that 30: 20: 20 kg·ha^{-1} NPK + 5 t manure produced similar yields to 60: 40: 40 kg·ha^{-1} NPK + 2.5 t manure implied that mineral fertilizer could be reduced and supplemented with manure without sacrificing grain yield. Combined 30: 20: 20 kg·ha^{-1} NPK + 2.5t manure produced grain yield similar

Table 3 Effect of manure and mineral fertilizer on maize grain yield.

Fertilizer (kg·ha^{-1} NPK)	Grain yield (kg·ha^{-1})
0: 0: 0	1,249
30: 20: 20	2,502
60: 40: 40	3,618
F pr (0.05)	> 0.001
Manure (t/ha)	
0	1,400
2.5	2,515
5	3,451
F pr (0.05)	> 0.001
LSD (0.05)	317.10
F pr (fertilizer*manure)	0.001
CV (%)	12.9

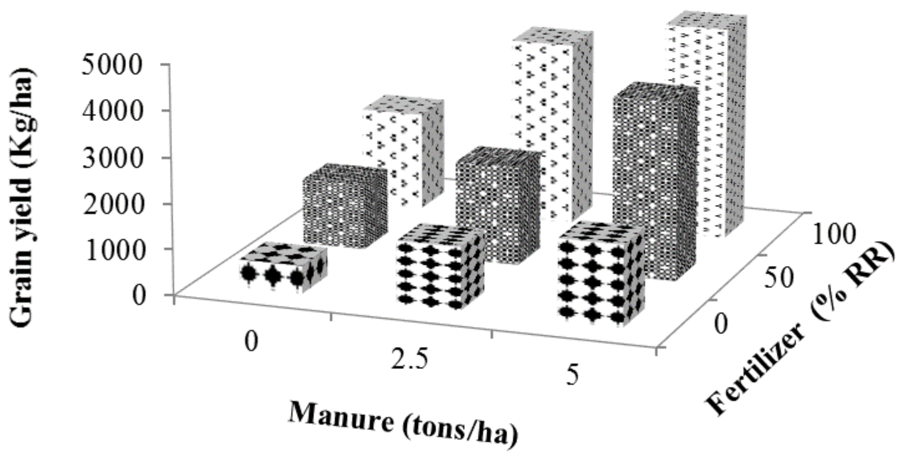

Fig. 1 Combined effect of manure and mineral fertilizer application on maize grain yield.

to 60: 40: 40 kg·ha^{-1} NPK due to the ability of manure to condition the soil for effective utilization of fertilizer nutrients. It has been reported that the precise application of manure and mineral fertilizer to maize could be as effective as commercial N fertilizer for yield response [7].

3.2 Effect of Combined Application of Manure and Mineral Fertilizer on Added Benefit in Maize Grain Yield

The highest rate of manure (60: 40: 40 kg·ha^{-1} NPK + 5 t manure) might have improved soil organic matter and CEC for effective adsorption of fertilizer nutrients by soil and subsequent absorption by maize leading to an improved synergistic interaction and the highest added benefits in grain yield (Fig. 2). Perhaps the high quality N (N = 2.75%) of the manure used in this study [9] coupled with the adequate amount of rainfall at grain filling stage accounted for such interaction. It has been reported that a synergistic interaction between organic and inorganic resources could be the result of priming effect on soil nutrients caused by an enhancement in soil microbial and enzyme activities [7]. In contrast to the report of Mucheru, M. et al. [1] and Vanlauwe, B. et al. [3] that when the manure applied is of high quality (N% > 2.50) and there's enough rain at grain filling stage, synergistic interaction occurs, an added disadvantage of 44 kg·ha^{-1} was accrued from 30: 20: 20 kg·ha^{-1} NPK + 2.5 t manure. This finding could therefore be attributed to the low nutrients supplied through the lower rates of the NPK and manure in 50 % NPK + 2.5 t manure.

3.3 Cost Effectiveness of Combined Manure and Mineral Fertilizer Application

The applications of 60: 40: 40 kg·ha^{-1} NPK + 2.5 t manure and 30: 20: 20 kg·ha^{-1} NPK + 5t manure were the most economically viable nutrient inputs per the economic viability threshold (2) set by Food and Agriculture Organization [15]. This was because the nutrient inputs interacted synergistically, resulting in yields that compensated for the costs associated with those nutrient inputs. The highest VCR (2.0) from 60: 40: 40 kg·ha^{-1} NPK + 5 t manure and 30: 20: 20 kg·ha^{-1} NPK + 5 t manure (Fig. 3) implied that resource poor farmers could at least reduce mineral fertilizer by at most 50% and supplement with available high quality manure without compromising grain yield.

4. Conclusion

The application of 60: 40: 40 kg·ha^{-1} NPK + 5 t manure performed best in terms of maize grain yield. The use of 60: 40: 40 kg·ha^{-1} NPK + 5 t manure, 60: 40: 40 kg·ha^{-1} NPK + 2.5 t manure and 30: 20: 20 kg·ha^{-1} NPK + 5 t manure realized synergistic

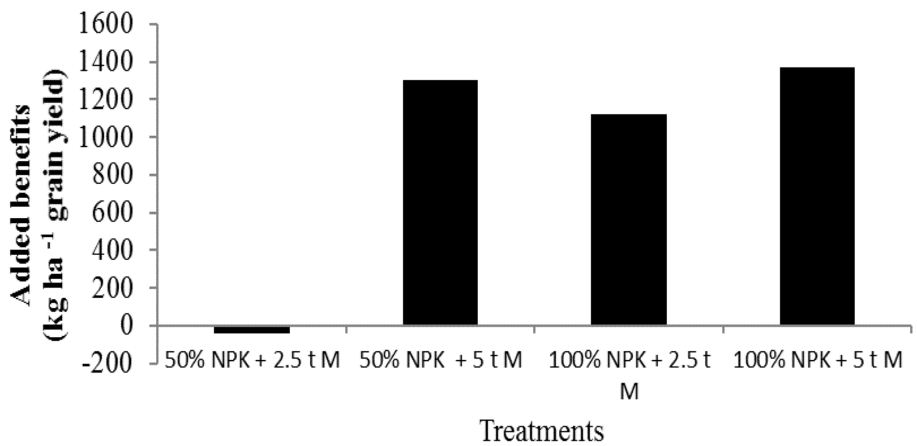

Fig. 2 Added benefit from combined manure and mineral fertilizer application.

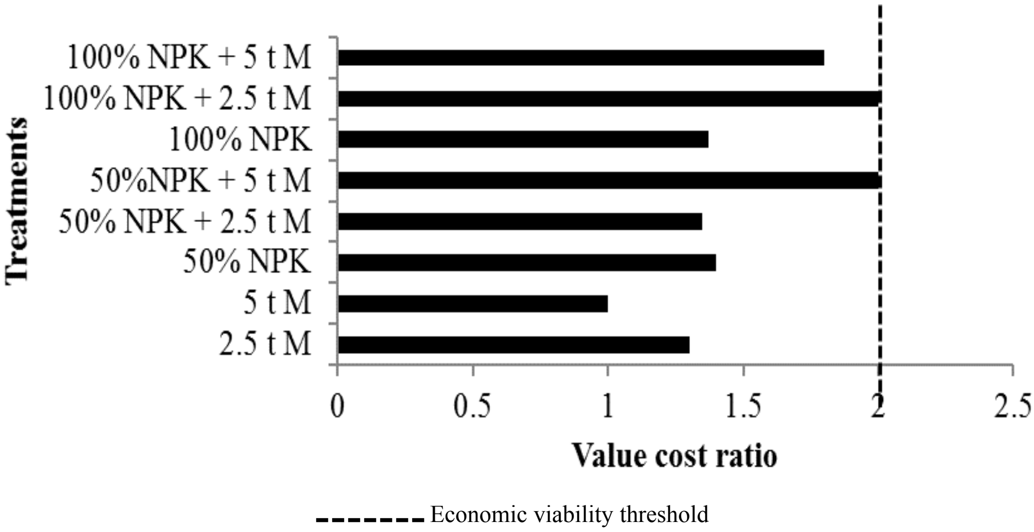

Fig. 3 VCR of the applied treatments.

interactions with the greatest added benefit in grain yield (1,371 kg·ha^{-1}) from 60: 40: 40 kg·ha^{-1} NPK + 5 t manure. The use of 30: 20: 20 kg·ha^{-1} NPK + 2.5 t manure led to antagonistic interactions of 44 kg·ha^{-1} of grain yield. The economic analysis showed that 30: 20: 20 kg·ha^{-1} NPK + 5 t manure was the most economically viable treatment (VCR = 3.89)

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