Combining inorganic fertilizer with poultry manure for sustainable production of quality protein maize in Ghana

H. K. DAPAAH, S. A. ENNIN & J. N. ASAFU-AGYEI
CSIR-Crops Research Institute, P. O. Box 3785, Kumasi, Ghana

ABSTRACT

Field studies were used, in the major and minor seasons of 2002 and 2003 at Fumesua (forest zone) and Ejura (transition zone), to determine the effects of combining inorganic fertilizer with poultry manure on grain yield stability and economic benefits of quality protein maize (QPM) production. The experimental design was a randomized complete block with four replicates. The treatments were (i) recommended inorganic fertilizer rate (IFR) (76 kg N ha^{-1}); (ii) recommended poultry manure (PM) (3 t PM ha^{-1}); (iii) 57 kg N ha^{-1} + 0.75 t PM ha^{-1} (i.e. ¾ IFR + ¼ PM); (iv) 38 kg N ha^{-1} + 1.5 t PM ha^{-1} (i.e. ½ IFR + ½ PM); (v) 19 kg N ha^{-1} + 2.2 t PM ha^{-1} (i.e. ¼ IFR + ¾ PM); and (vi) no fertilizer (control). An open-pollinated QPM variety *Obatanpa* was used. Averaged over all seasons and locations, grain yield for the recommended IFR was 3.31 t ha^{-1}, similar to grain yields of 3.22 and 3.10 t ha^{-1} for the ½ IFR + ½ PM and ¼ IFR + ¾ PM treatments, respectively. However, these treatments together yielded 7-14 per cent higher than the yields produced at 3 t PM and ¾ IFR + ¼ PM; and 32-38 per cent higher than the control. The yields at ¼ IFR + ¾ PM and recommended IFR were most stable across all environments, with mean yields above the grand mean and regression coefficients less than but close to 1.0. The ¼ IFR + ¾ PM and ½ IFR + ½ PM recorded the highest net benefits and marginal rate of returns (MRR) of 187 - 349 per cent over 3 t PM ha^{-1}. The recommended IFR and ¾ IFR + ¼ PM treatments had lower net benefits, but higher total variable costs than the ¼ IFR + ¾ PM and ½ IFR + ½ PM; and, therefore, were dominated by the latter.

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RÉSUMÉ

DAPAAH, H. K., ENNIN, S. A. & ASAFO-AGYEI, J. N.: *Combinaison d' engrais inorganique avec le fumier de volaille pour une production durable de maïs protéique de qualité au Ghana.* Des études ont été entreprises pendant les saisons majeures et mineures en les années 2002 et 2003 à Fumesua (zone forestière) et à Ejura (zone transitionnelle) pour déterminer les effets de la combinaison d' engrais inorganique avec le fumier de volaille sur la stabilité de rendement de grain et les bienfaits économiques de la production de maïs proteique de qualité (MPQ). Le dessin expérimental était un bloc complet choisi au hasard avec quatre replicatifs. Les traitements étaient: (i) Le taux d' engrais inorganique (TEI) recommandé (76 kg A ha^{-1}); (ii) Le fumier de volaille (FV) recommandé (3 t FV ha^{-1}); (iii) 57 kg A ha^{-1} + 0.75 t FV ha^{-1} (i.e. ¾ TEI + ¼ FV); (iv) 38 kg A ha^{-1} + 1.5 t FV ha^{-1} (i.e. ½ TEI + ½ FV); (v) 19 kg A ha^{-1} + 2.2 t FV ha^{-1} (i. e. ¼ TEI + ¾ FV); et (vi) engrais nul (le contrôle). "Obatanpa", une variété de MPQ de pollinisation libre était utilisée. Faisant la moyenne de toutes les saisons et de tous les emplacements, le rendement de grain pour le TEI recommandé était 3.31 t ha^{-1}, semblable aux rendements de grain de 3.22 et 3.10 t ha^{-1} obtenu respectivement de traitements ½ TEI + ½ FV et ¼ TEI + ¾ FV. Cependant ces traitements ensemble rendaient 7-14% plus élevés que les rendements produits à 3 t FV et ¾ TEI + ¼ FV; et 32-38% plus élevé que le contrôle. Les rendements ¼ TEI + ¾ FV et TEI recommandé étaient les plus stables à travers tous les environments, avec les rendements moyens au-dessus du moyen global et les coefficients de régression moins que mais près de 1.0. Le ¼ TEI + ¾ FV et ½ TEI + ½ FV donnaient les bienfaits nets les plus élevés et les proportions marginales de rentabilité (PMR) de 187% - 349% par rapport à 3 t FV ha^{-1}. Le TEI recommandé et ¾ TEI + ¼ FV traitements avaient les bienfaits nets plus faibles, mais de coûts variables totaux plus élevés que le ¼ TEI + ¾ FV et ½ TEI + ½ FV; et par conséquent étaient dominés par le dernier.

Introduction

Maize is a major staple food crop in Ghana, and is extensively grown in the forest and transition agro-ecological zones. Low soil fertility is one of the major constraints affecting the production of maize and other food crops in Ghana. In many maize or cereal-growing areas, grain yields are very low without fertilizer application. Maize yields in farmers' fields are often less than 1 t ha^{-1}, while the maize cultivars grown have a potential of over 4 t ha^{-1} (GGDP, 1996). The few farmers who apply some inorganic fertilizer do not apply adequate amounts of the recommended inorganic fertilizer rates (IFR), citing the high cost of the input. The tendency to shift cultivation is, therefore, high; but land is no longer abundant to meet such a desire. Organic fertilizer sources such as poultry manure are available, but very much underused in maize production. Some poultry farms burn their manure as a disposal strategy, causing some environmental concerns. To increase crop production in West Africa, inorganic and organic inputs are needed (Buresh, Sanchez & Calhoun, 1997; FAO, 1999). The use of organic manure to supplement inorganic fertilizer, as an integrated nutrient management strategy, is thus of paramount importance for sustained food crop production.

Several hypotheses have been formulated concerning possible positive interactions between inorganic and organic inputs when applied together (Giller, Cadisch & Mugwira, 1998; Palm, Myers & Nandwa, 1997). Very limited information exists on the combination of inorganic and organic fertilizer effects on crop yields in southern Ghana. However, Abunyewa *et al*. (1998) reported from studies in the Guinea savanna zone of northern Ghana that combinations of organic manure (cow dung) at 4 and 8 t ha^{-1} with 60-40-40 kg ha^{-1} N-P_2O_5-K_2O increased maize yields by 30 , 28 and 21 per cent over no fertilizer, cow dung only, and inorganic fertilizer only, respectively in the 1st year. In the 2nd year, the increases were 72 , 61 and 32 per cent higher, respectively.

This paper focuses on the use of combined inorganic fertilizers and poultry manure as components of an integrated nutrient management strategy to improve maize yields in smallholder farms.

The objectives of the study were, thus, to determine the combined effects of inorganic fertilizer and poultry manure on grain yield, yield stability, and economic benefits of quality protein maize (QPM) production.

Materials and methods

The study was at Fumesua (forest zone) and Ejura (transition zone) in the major and minor seasons of 2002 and 2003. Table 1 shows details of the agro-ecological characteristics of the locations. The experimental design was a randomized complete block with four replications. The treatments were (i) recommended inorganic fertilizer rate (IFR) (76 kg N ha^{-1}); (ii) recommended poultry manure (PM) (3 t PM ha^{-1}); (iii) 57 kg N ha^{-1} + 0.75 t PM ha^{-1} (¾ IFR + ¼ PM); (iv) 38 kg N ha^{-1} + 1.5 t PM ha^{-1} (½ IFR + ½ PM); (v) 19 kg N ha^{-1} + 2.2 t PM ha^{-1} (¼ IFR + ¾ PM); and (vi) no fertilizer (control).

An open-pollinated QPM variety *Obatanpa* was planted at 80 cm between-rows and 40 cm within-rows at two plants per hill on the dates shown in Table 1. Six-row plots were used, with each row 5 m long. The inorganic fertilizer rates were applied as 20:20:0 N:P:K starter (at 66% of N applied per treatment) at 7 days after planting (DAP), and sulphate of ammonia as top-dress (at 34% of N applied per treatment) at 28 DAP. The PM was spot-applied and buried at 7 DAP in both seasons and years. Ears were harvested from the two central rows and the yield calculated for 15 per cent moisture from the moisture content at harvest.

The yield data from the locations and seasons were used to estimate the stability parameters of each treatment according to the regression model suggested by Eberhart & Russell (1966) and Thiaw, Hall & Parker (1993). Soil samples were taken from a depth of 0 to 20 cm at the beginning of each season, and were analyzed for total N,

TABLE 1

Agroecological Characteristics of the Experimental Locations

Characteristic	*Location*	
	Fumesua	*Ejura*
Coordinates	6° 41′ N, 1° 28′ W	7° 23′ N, 1° 21′ W
Agroecological zone	Humid forest	Forest-savannah transition
Soil types	Ferric Acrisol*	Dystric Cambisol*
	Asuansi series with about 5-cm thick top layer of dark-grey gritty loam to gritty clay loam	Ejura series with about 20-30-cm thick top layer of loamy soils
Slope gradient	2-6%	2-6%
Temperature range (min-max °C)	22-31	21-34
Wet season – major-minor	Mar-Jul	Mar-Jul
	Aug-Nov	Aug-Nov
Total rainfall (mm)		
2002 – major-	847 (7 May 2002)‡	813 (3 May 2002)
minor	331 (2 Aug 2002)	456 (6 Aug 2002)
2003 – major-	749 (13 May 2003)	588 (19 May 2003)
minor	287 (12 Aug 2003)	506 (26 Sep 2003)

* FAO/UNESCO classes; FAO/UNESCO (1988)
‡ Planting dates in parenthesis

available P and K, organic carbon and matter. The available P was determined in a Bray 1 extract as described by Olsen & Sommers (1982). Similarly, the poultry manure was analyzed at the beginning of each season. The poultry manure was digested in concentrated H_2SO_4, and portions of aliquots were taken to determine total N, P, K, Ca and Mg (Soil Laboratory Staff, 1984). Partial budget analysis, using information presented in Table 2, was used to estimate the net benefits (NB) of the treatments and the marginal rates of return (MRR) to determine the benefits to farmers (CIMMYT, 1988). The net benefit and MRR were calculated as follows:

Net benefit (NB) = Total gross benefit (TGB) – Total variable cost (TVC)

$$MRR = (\Delta NB/\Delta TVC) \times 100$$

The MRR is the increased benefit of a treatment as a percentage of the increased cost. Dominance analysis was also applied. A treatment with a lower NB, but a higher TVC compared to another treatment is said to be dominated. All statistical analyses were applied using the Statistical Analysis Systems Institute (SAS)

TABLE 2

Information Used for the Partial Budget Analysis

Variable	*Quantity/Amount*
1. Farm gate price of maize (t^{-1})	¢1,500,000.00
2. Fertilizer cost	
1 bag (50 kg) of 20-20-0 NPK	¢120,000.00
1 bag (50 kg) of sulphate of ammonia	¢80,000.00
3. Poultry manure cost (1 ton)	¢100,000.00
4. Labour for inorganic fertilizer and poultry manure application	10 mandays ha^{-1}
Labour cost for application ($manday^{-1}$)	¢15,000.00
5. Transportation cost	
1 bag (50 kg) of inorganic fertilizer	¢3,000.00
1 ton poultry manure	¢30,000.00

1 US$ = ¢9,000.00

package (SAS, 1988). Each season in a given location was treated as individual environment in the analysis of variance.

Results and discussion

Soil and poultry manure characteristics

Table 3 presents the chemical properties of the soils at the sites (0-20 cm depth) and the characteristics of the poultry manure used. The *p*H of the soils ranged from 5.1 to 6.1, indicating the soils were slightly acidic. Total N was very low to low in the rating of Landon (1996). The levels of available P were moderate at Fumesua in all seasons, and at Ejura in 2002 (14.7-20.2 mg kg^{-1}); but was high at Ejura in 2003 (> 20 mg kg^{-1}). The critical P value for maize is 10-16 mg kg^{-1} (Adeoye & Agboola, 1985; Landon, 1996). Available K levels were moderate and adequate for maize production (Landon, 1996). The poultry manure used was collected from the same poultry farm for both years and seasons, and used for both locations. The PM had N, P and K ranges of 2.5 to 2.6, 0.96 to 0.98 and 1.40 to 1.44 per cent, respectively; and a *p*H of 7.3 to 7.7 (i.e. neutral to slightly alkaline). At these composition levels, the recommended PM rate (3 t ha^{-1}), for example, provided 78 kg N ha^{-1}, 30 kg P ha^{-1} and 42 kg K ha^{-1}, equal to that provided by the recommended IFR.

Grain yield and yield stability

Mean grain yield among the environments ranged from 1.45 to 4.91 t ha^{-1} (Table 4). Grain yields ranged from 2.02 to 4.91 t ha^{-1} for Fumesua, and 1.45 to 4.53 t ha^{-1} for Ejura. The grain yields produced in the major seasons (3.05-5.84 t ha^{-1}) were generally higher than grain yields in the minor seasons (1.27-2.86 t ha^{-1}) in both locations and years, except for Ejura 2003 (Table 4). The low moisture experienced during the silking and grain-filling stages at Ejura in 2003 major season may have been responsible for the relatively low yields.

TABLE 3

Soil Chemical Properties at the Sites and Characteristics of Poultry Manure Used

Soil chemical property	*Fumesua*				*Ejura*			
	2002		*2003*		*2002*		*2003*	
	Maj‡	*Min*	*Maj*	*Min*	*Maj*	*Min*	*Maj*	*Min*
*p*H (1:2.5 H_2O)	5.1	5.9	6.1	5.9	5.7	5.2	5.2	5.3
Elect. conduct. (mS cm^{-1})	0.35	0.34	0.29	0.47	0.31	0.32	0.40	0.38
Total N (%)	0.11	0.09	0.10	0.10	0.03	0.04	0.03	0.03
Organic C (%)	1.37	1.08	1.15	1.21	0.32	0.45	0.35	0.38
Organic M (%)	2.36	1.86	1.98	2.08	0.55	0.77	0.60	0.70
Available P (mg kg^{-1})	19.5	18.1	17.4	14.7	20.2	16.0	29.3	25.8
Available K (mg kg^{-1})	54.3	41.4	43.7	32.7	28.1	20.2	87.4	80.5

Poultry manure characteristic

	N	*P*	*K*	*Ca*	*Mg*	*Organic C*	*Moisture content*	*Dry matter*	p*H*	*C:N ratio*
	%								1:2.5 H_2O	
2002	2.60	0.98	1.44	3.49	2.92	40.6	10.8	89	7.7	16:1
2003	2.50	0.96	1.40	3.49	2.92	39.0	10.5	85	7.3	15:1

‡ Maj = major season
Min = minor season

TABLE 4

Maize Grain Yield as Affected by Combinations of Inorganic Fertilizer and Poultry Manure Grown in Eight Environments

	Grain yield (t ha^{-1})			
	2002		2003	
Treatment	*Major*	*Minor*	*Major*	*Minor*
		Fumesua		
IFR at 76 kg N ha^{-1}	4.85	2.81	3.82	3.32
PM at 3 t ha^{-1}	5.46	1.85	2.66	1.96
57 kg N ha^{-1} + 0.75 t PM ha^{-1}	4.79	2.29	3.21	1.85
38 kg N ha^{-1} + 1.5 t PM ha^{-1}	5.84	1.90	3.64	2.49
19 kg N ha^{-1} + 2.2 t PM ha^{-1}	5.07	1.99	2.83	2.73
Control (no fertilizer)	3.42	1.27	3.08	1.71
Mean	4.91	2.02	3.21	2.34
		Ejura		
IFR at 76 kg N ha^{-1}	5.00	2.86	1.53	2.32
PM at 3 t ha^{-1}	4.11	2.26	1.27	2.50
57 kg N ha^{-1} + 0.75 t PM ha^{-1}	4.78	2.19	1.31	2.62
38 kg N ha^{-1} + 1.5 t PM ha^{-1}	5.39	2.20	1.75	2.54
19 kg N ha^{-1} + 2.2 t PM ha^{-1}	4.83	3.02	2.23	2.08
Control (no fertilizer)	3.05	1.27	0.57	1.97
Mean	4.53	2.30	1.45	2.34
Location (L)	P = 0.0038		SED = 0.091	
Year (Y)	P = < 0.0001		SED = 0.091	
Season (S)	P = < 0.0001		SED = 0.091	
Treatment (T)	P = 0.0001		SED = 0.158	
Significant interactions				
L × Y	P = 0.0002		SED = 0.129	
L × S	P = < 0.0001		SED = 0.129	
Y × S	P = < 0.0001		SED = 0.129	
L × Y × S	P = 0.0328		SED = 0.183	

Averaged across locations, years and seasons, the treatments with ½ IFR + ½ PM and ¼ IFR + ¾ PM produced yields of 3.22 and 3.10 t ha^{-1}, respectively; similar to the 3.31 t ha^{-1} yield of the recommended IFR of 76 kg N ha^{-1} (Table 4). These together yielded 7-14 per cent higher than the 3 t PM ha^{-1} and 57 kg N ha^{-1} + 0.75 t PM ha^{-1} treatments; and 32-38 per cent higher than the control. The recommended IFR yielded 17 per cent higher than the recommended PM.

Generally, combining poultry manure with inorganic fertilizer across the environments did not elicit an additive response in maize yield, because yields did not differ significantly from the recommended IFR alone treatment. However, application of ½ IFR (38 kg N ha^{-1}) + ½ PM (1.5 t PM ha^{-1}) or ¼ IFR (19 kg N ha^{-1}) + ¾ PM (2.2 t PM ha^{-1}) combinations were as effective as the recommended IFR. Gitari & Friesen (2001) had similar results, with the application of NP fertilizer at ½ the recommended rate combined with farm yard manure (FYM) either at the full or ½ the recommended rate being as effective as the full NP rate. However, in contrast, Abunyewa *et al.* (1998) found that the combination of cow dung and inorganic fertilizer yielded higher (21-32 %)

TABLE 5

Mean Yields and Estimates of Stability Parameters for Yield of Maize Grown Over Eight Environments, 2002-2003

Treatment	*Mean yield ($t\ ha^{-1}$)*	*b*	*SE of b (df = 6)*	*EMS (× 10^3)*	r^2
IFR at 76 kg N ha^{-1}	3.31	0.93	± 0.124	162.43	0.90
PM at 3 t ha^{-1}	2.76	1.07	± 0.113	136.69	0.94
57 kg N ha^{-1} + 0.75 t PM ha^{-1}	2.88	1.03	± 0.089	83.30	0.96
38 kg N ha^{-1} + 1.5 t PM ha^{-1}	3.22	1.28	± 0.064	43.65	0.99
19 kg N ha^{-1} + 2.2 PM ha^{-1}	3.10	0.92	± 0.136	197.10	0.88
Control (no fertilizer)	2.04	0.77	± 0.130	181.02	0.85
Mean	2.89				
SED	0.158				

than inorganic fertilizer only in northern Ghana.

Table 5 presents estimates of stability parameters. Treatments with high mean yields and regression coefficients less than or close to 1.0 and deviations from regression (or error mean square) as small as possible ($S^2d = 0$) are considered stable. Maize yields were most stable for the recommended IFR and 19 kg N ha^{-1} + 2.2 t PM ha^{-1}, with regression coefficients of 0.93 and 0.92, respectively (Table 5). These treatments also had mean yields across the environments above the grand mean (3.31 and 3.10 versus 2.89 t ha^{-1}), indicating good performance across all the environments. The no-fertilizer control had a regression coefficient of less than 1.0 (i.e. b = 0.77) and a lower mean yield than the grand mean, indicating adaptation to poorer environments. However, the recommended PM, 57 kg N ha^{-1} + 0.75 t PM ha^{-1} and 38 kg N ha^{-1} + 1.5 t PM ha^{-1}, had regression coefficients greater than 1.0 (Table 5) and yields similar or higher than the grand mean, indicating adaptation to favourable environments. The coefficient of determination values (Table 5) suggest that 85-99 per cent of the variation in yield was accounted for by variation in growing environments. Tariq *et al.* (2003) reported similar results in maize, and Assefa, Gelete & Tanner (1995) in wheat.

Economic analysis

The economic analysis was based on the costs provided in Table 2. The grain yields were adjusted by 10 per cent in the analysis (Table 6), to approximate the yield that farmers could obtain on their farms (Alimi & Manyong, 2000). This was necessary to prevent overestimation of the returns that farmers were likely to obtain from a treatment. In addition, the experimental fields usually had higher management levels, smaller plot sizes, precision in harvesting, and better harvesting methods. The analysis showed that all treatments were economically attractive, because they had positive net benefits (Table 6). However, the 38 kg N ha^{-1} + 1.5 t PM ha^{-1} and 19 kg N ha^{-1} + 2.2 t PM ha^{-1} treatments had the highest net benefits (Table 6). The control, as expected, recorded the least net benefit. The dominance analysis showed that 57 kg N ha^{-1} + 0.75 t PM ha^{-1} and the recommended IFR had lower net benefits, but higher total variable costs than the 38 kg N ha^{-1} + 1.5 t PM ha^{-1} and 19 kg N ha^{-1} + 2.2 t PM ha^{-1} treatments; and, therefore, were dominated. Applying the recommended PM over the control gave a marginal rate of return (MRR) of 80 per cent, while applying 19 kg N ha^{-1} + 2.2 t PM ha^{-1} over the recommended PM gave a MRR of 349 per cent (Table 6). This indicates that for every ¢100.00 invested, for example, in adopting 19 kg N ha^{-1} + 2.2 t PM ha^{-1}over recommended PM, the farmer gets an additional gain of ¢249.00. Therefore, the 38 kg N ha^{-1} + 1.5 t PM ha^{-1} and 19 kg N ha^{-1} + 2.2 t PM ha^{-1} treatments are

TABLE 6

Partial Budget Analysis for Maize as Affected by Inorganic Fertilizer and Poultry Manure Grown Over Eight Environments

	IFR at 76 kg N ha^{-1}	*PM at 3 t ha^{-1}*	*57 kg N ha^{-1} + 0.75 t PM ha^{-1}*	*38 kg N ha^{-1} + 1.5 t PM ha^{-1}*	*19 kg N ha^{-1} + 2.2 t PM ha^{-1}*	*Control (no fert.)*
Gross benefit						
Yield (t ha^{-1})	3.31	2.76	2.88	3.22	3.10	2.04
Adjusted yield (90%) (t ha^{-1})	2.979	2.484	2.592	2.898	2.790	1.836
Total gross benefit (TGB) (¢ × 10^3 ha^{-1})	4468.5	3726	3888	4347	4185	2754
Variable cost						
Fertilizer cost (¢ × 10^3 ha^{-1})						
20:20:0	600	0	450	300	150	0
Sulphate of ammonia	200	0	150.4	100	50.4	0
Poultry manure	0	300	75	150	220	0
Application cost (IFR + PM) (¢ × 10^3 ha^{-1})	150	150	150	150	150	0
Transportation cost (¢ × 10^3 ha^{-1})						
IFR	22.5	0	16.89	11.25	5.64	0
PM	0	90	22.5	45	66	0
Total variable cost (TVC) (¢ × 10^3 ha^{-1})	972.5	540	864.79	756.25	642.04	0
Net benefit (TGB – TVC) (¢ × 10^3 ha^{-1})	3496	3186	3023.21	3590.75	3542.96	2754
Marginal rate of return (MRR)	*Control*	*PM at 3 t ha^{-1}*	*19 kg N ha^{-1} + 2.2 t PM ha^{-1}*	*38 kg N ha^{-1} + 1.5 t PM ha^{-1}*	*57 kg N ha^{-1} + 0.75 t PM ha^{-1}*	*IFR at 76 kg N ha^{-1}*
TVC (¢ × 10^3 ha^{-1})	0	540	642.04	756.25	864.79	972.5
Net benefit (¢ × 10^3 ha^{-1})	275.4	3186	3542.96	3590.75	3023.21	3496
MRR (%) = $\frac{\triangle NB}{\triangle TVC} \times 100$		80	349	42 (187)†	D*	D

* Dominated ; † MRR of 38 kg N ha^{-1} + 1.5 t PM ha^{-1} over PM at 3 t ha^{-1}; 1US$ = ¢9,000.00

recommended for high net benefits and MRR.

Conclusion

The results clearly indicate that the use of combined inorganic and organic fertilizers produced similar maize yields as inorganic fertilizer alone. The yield stability and economic analyses indicated that 19 kg N ha^{-1} + 2.2 t PM $ha^{-1}$and 38 kg N ha^{-1} + 1.5 t PM ha^{-1} were stable and economically viable options to fully recommended IFR for adoption across the forest, transition, or similar representative environments. Therefore, in 2004 and 2005, the two treatments (19 kg N ha^{-1} + 2.2 t PM $ha^{-1}$and 38 kg N ha^{-1} + 1.5 t PM ha^{-1}) were tested as verification-demonstration trials at over 20 locations in farmers' fields on-farm in the two agro-ecological zones.

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