Informed site-specific fertilizer recommendation for upland rice production in northern guinea savannah of Nigeria


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Abstract

Despite the overwhelming recognition by small-holders of the important role of mineral fertilizer in rice farming, the average fertilizer use in Nigeria is far below crop requirement for sustainable production. This is because of generalized recommendations for broad areas that take no account of the complexity and diversity of farmers operating contexts. There is a need to develop 'à la carte' fertilizer recommendations and strengthen the farmers' understanding of mineral fertilizer to allow them to fine-tune and pick the most suitable recommendation given their soil type and their economic circumstances. One of the projects of the Sub-Saharan Africa Challenge Programme has set out to improve fertilizer use within rice farming communities in the northern guinea savannah (NGS) zone of Nigeria by engaging farmer communities through participatory learning and action-research using nutrient-omission trials as one of the main tools. Farmers installed 'nutrient-omission plots' in part of their fields on the major soil types of the area. The results revealed that the most limiting nutrient on most soils in the pilot villages was nitrogen, followed by phosphorus. Discussions about the results among actors led to 'à la carte' recommendation options tailored to meet farmers' financial capacities and production goals. These alternative options were evaluated by farmer groups prior to their dissemination.

Introduction

Important staple food for billions of peoples around the world, rice is consumed by about 140 million Nigerians. It is well appreciated by small-holder farmers. About 2 140 820 ha of land are devoted to rice production in Nigeria, producing an estimated 3 543 510 tonnes (NAERLS and NFRA, 2009).

However, important yield decreases are reported by farmers, a major concern for small-holder rice farmers and researchers in sub-Saharan Africa. Soil nutrient depletion is among the causes of yield decrease. Stoorvogel and Smaling (1990) estimated annual net depletion in excess of 30 kg N and 20 kg K/ha for arable land in Nigeria. The same cause is often cited in the northern guinea savannah (NGS) of Nigeria (Adejobi and Kormawa, 2002). Most farmlands are degraded by erosion that washes away soil nutrients; harvested products (including crop residues) are often taken out of the field and fertilizer applications are insufficient or not properly carried out (Ahmed *et al.*, 2009).

Rice farmers are aware of the importance of fertilizers (organic and/or inorganic) in providing consistent benefit from farming activity. But subsistence farming (consisting of sub-optimal use of fertilizers and other soil management practices) leaves little opportunity for farmers to afford fertilizers to replace nutrients removed from their soils through harvested crops. They usually apply cow dung on their farms prior to crop establishment and some mineral fertilizers. However, quantities applied are below upland rice nutrient requirements in the area. Manyong *et al.* (2001) reported an average application of only 40 kg N/ha in northern Nigeria. Average applications of nutrients in the NGS were in the ranges 26.75–30.5 kg N, 1.64–3.28 kg P and 3.12–6.25 kg K/ha for upland rice production (Ezui *et al.*, 2008).

These values are low considering that for the production of 1 tonne of upland rice paddy, rice needs to take up 15–40 kg N, 0.8–3.5 kg P and 14.3–40 kg K per hectare (Koopmans, 1990), which correspond to the application of 51–133 kg N, 8–35 kg P and 48–133 kg K/ha for a recovery fraction of 30% N, 10% P and 30% K applied. They are also far below the generalized recommendation of 76 kg N, 13 kg P and 25 kg K/ha, regardless of soil type. Many reasons may explain the lack of adoption of full-dose fertilization, including poor response under certain circumstances, the cost of the fertilizer at recommended rate being beyond the reach of farmers, and farmers' lack of proper fertilizer-management skills. As a result, low average paddy yields are recorded: 0.7 t/ha on uplands (Ahmed *et al.*, 2009), compared to the national average of about 1.5 t/ha (Fashola *et al.*, 2006). Thus, there is a need to develop appropriate fertilizer recommendations that are flexible enough to address the farmers' diverse circumstances.

The research work reported here aims at facilitating the adoption of fertilizer recommendations by farmers through improving their understanding of mineral fertilizer and the formulation of site-specific fertilizer recommendations.

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Materials and methods

Study area

The work was conducted in an upland rice production area, Dandume Local Government Area (11°27.520′ N, 7°07.838′ E, 2303 feet [702 m] above sea level), Katsina State, Nigeria, in the framework of the Kano–Katsina–Maradi (KKM) project in NGS. Characteristic of the NGS agro-ecological zone, this area is characterized by a landscape with gentle and sinuous slope, an average rainfall of about 900–1300 mm per year, with an average daily temperature of 30°C in summer (warm and rainy, from May to November) and 20°C in winter (cold and dusty, from December to April). Soils are often very poor and subjected to many degradation phenomena, mainly nutrient mining. Rice, maize, soybean, sorghum, cotton and pepper are the main cash crops, while the food crops are maize, rice, sorghum, cocoyam and millets.

Nutrient-omission trial

Experimental design

Five treatments were set up with the participation of the learning group (participating farmers). In each community, at least 10 farmers were involved, each implementing a replicate of the trial. The treatments were:

- T0: Control (no fertilizer)
- T1: No nitrogen: 0 kg N – 40 kg P – 40 kg K/ha
- T2: No phosphorus: 100 kg N – 0 P – 40 kg K/ha
- T3: No potassium: 100 kg N – 40 kg P – 0 kg K/ha
- T4: 100 kg N – 40 kg P – 40 kg K/ha.

These five treatments were established according to a completely randomized design on the farms of 10 rice growers per major upland soil type in the three pilot villages on 6 × 6 m plots. Upland rice variety NERICA 1 was used for this trial. It was established using dibbling planting method at 25 cm between lines and 20 cm between plants within lines between June and early July in 2008 and 2009, and harvested at maturity in September of each year. The farmers were responsible of all operations from planting to harvest with the coaching of extension service technicians trained prior the growing season for this purpose. The farmers were advised and supported to provide good care to avoid management limitation to the crop performance. Phosphorus (P) and Potassium (K) based fertilizers were broadcast and incorporated before planting, while urea was applied twice at 2 and 6 weeks after planting (WAP).

Data analysis

Composite soil samples were taken at two levels (0–15 cm and 15–30 cm) prior to crop establishment for laboratory analysis. During the growing period, crop vigor, plant height and leaf color were measured at 3, 6 and 9 WAP, in addition to panicle load at maturity. The paddy and straw yields were recorded at maturity. Plant tissue analyses were undertaken per plot for N, P and K content. Statistical analyses were implemented using STATISTICA software (StatSoft Inc., 1999). The most limiting nutrient was determined as the lowest yield obtained across treatments T1, T2 and T3 (the nutrient-omission plots). The indigenous soil nutrient supply (IS) was deducted from biomass uptake on these plots.

Site-specific fertilizer recommendation and validation

The fertilizer recommendations were made by providing the most limiting nutrients. As K was the least limiting factor, the main purpose of the trial was to confirm the nutrient-omission trial results and to determine a K management option when P and N are supplied sufficiently. So, on the basis of 6 fertilizer bags as the generalized recommendation (4 NPK + 2 urea), the nutrient-omission-trial-based recommendations provided 6 bags of N- and P-based fertilizers only (V2 and V4). In addition to this, the added effect of K was tested by applying an extra bag of muriate of potash (MOP) (V3 and V5). The following treatments were then tried out with farmers on 10 × 6 m plots:

- V0. FP: Farmer's practice (with or without fertilizer application)
- V1. 4 NPK + 2 urea (76 kg N, 13 kg P, 25 kg K/ha: the generalized fertilizer recommendation rate)
- V2. 4 urea + 2 TSP (triple super phosphate) (92 kg N, 20 kg P/ha: N and P single fertilizers based recommendation according to the nutrient-omission trial
- V3. 4 urea +2 TSP + 1 MOP (92 kg N, 20 kg P, 25 kg K/ha: treatment V2 + 1 bag MOP)
- V4. 3 DAP (diammonuim phosphate) + 3 urea (96 kg N, 30 kg P ha: N and P compound fertilizers based recommendation according to the nutrient-omission trial
- V5. 3 DAP + 3 urea + 1 MOP (96 kg N, 30 kg P, 25 kg K/ha: treatment V4 + 1 bag MOP).

The farmer's practice (V0) involved the use of a variety of the farmer's choice, which can be a local or an improved one bought from the market, their way of managing pests and diseases, their own fertilizer rates and timing of application if any, and any other 'personal' agronomic practices. For the remaining treatments (V1–

V5), NERICA 1 was used as improved variety, all planted by drilling method. The validation demonstration was conducted during the 2009 growing season in five villages (Gyazama, Mahuta, Dansoda, Dandume and Albasu).

The effectiveness of the recommended fertilizer rates was measured using the relative response (RR) criterion:

$$RRi\ (\%) = 100 \times \frac{(Yi - Y0)}{Y0}$$

Where RRi is the relative response due to treatment i, Yi and Y0 are the paddy yields obtained from treatment i and the control or farmer's practice treatment, respectively.

The added effect of the application of an additional fertilizer rate is measured by the formula:

$$AEf = \frac{(Yf - Yi0)}{Yi0}$$

Where Yf is the yield with additional fertilizer and Yi0 is the yield without the additional fertilizer.

The profitability of the recommended options related to fertilizer use was then analyzed in comparison to existing blanket recommendations of fertilizer rates and the farmers' practices using gross margin (GM), return on investment (RI) and value–cost ratio (VCR):

$$GM = (Yi \times Po) - FC$$

$$FCi = Qfi \times Pfi$$

Where Po is the average grain price on the market, FCi the cost of fertilizer i used, Qf the quantity of fertilizer and Pf the fertilizer price in the market.

$$RIi = \frac{GMi}{FCi}$$

$$VCR = (Yi - Y0) \times \frac{Po}{(FCi - FC0)}$$

Participatory learning

To enhance the farmers' understanding of fertilizer and the basis of fertilizer recommendations, some modules were developed to engage farmers in a participatory learning process enabling them:

- To analyze and characterize their soils;
- To acquire 'knowledge of fertilizers', allowing them to become familiar with fertilizers and to understand their role, particularly the role of each in rice production;
- To layout a 'questioning the soil experiment' (local name of nutrient-omission trial) to facilitate their comprehension of the effect of major nutrient limitations on rice crop performance. The principle was that 'when the yield on the omission plot is lower than that of the NPK plot, the omitted nutrient is limiting on that plot' and 'when the yield on the omission plot is as high as the NPK plot, the omitted nutrient is supplied sufficiently by the soil';
- To define 'performance indicators of rice cropping': Farmers were helped to select indicators and to develop tools (local symbols) to monitor the changes and differences between treatments;
- 'Participatory observations and evaluations' were conducted regularly, allowing farmers to observe and appreciate the performance of the crop on the farm and establish by themselves the effects of the different treatments of the 'questioning the soil experiment' (nutrient-omission trial). The consequences of the absence or presence of a nutrient were analyzed and discussed among the farmers and with other stakeholders. Each treatment was evaluated by a farmer or group of farmers according to each rice performance indicator (that they agreed on during the module on 'performance indicators of rice cropping') using 20 stones shared among the treatments with respect to their relative performance.

Results

Identification of soil resources

The participating farmers had the opportunity during the community analysis to characterize their soil types by describing the uplands soils and the type of crops cultivated there (Table 1). In the three villages, rice is mainly grown on uplands and covers more than 70% of land resources (Ezui *et al.*, 2008). The soils are mainly Alfisols

(Esu and Ojenuga, 1985), comprising two main textural characteristic soils: a sandy loam soil, locally named 'Jigawa', and a relatively poor clayey loam called 'Jangarigari'. Most of the farmers do not grow rice on *Jangarigari* in the area. *Jigawa* is also preferred for sorghum, maize, soybean and cowpea. *Jigawa* (Dansoda word) is known in Gyazama as 'Turbaya', and in Mahuta as 'Yarbuwa'.

Facilitation of the determination of the most limiting nutrient of upland rice production in Dandume LGA
Impact of the learning
The participatory learning was very useful for the determination of the most limiting nutrients by farmers.

- The 'Knowledge of fertilizers' module familiarized them with mineral fertilizers like triple super phosphate, super simple phosphate, muriate of potash and urea, and compound fertilizers like diammonium phosphate (DAP), NPK and natural rock phosphate. They all agreed to assign white, black and red colors to N, P and K fertilizers, respectively.
- The module on the layout of questioning the soil experiment gave a good understanding of the principle of the determination of the most limiting nutrients for rice yields and the related symptoms.
- The module on the performance indicators of upland rice cropping helped design a form for the participatory observation and evaluation. The main indicators retained were: plant height, crop vigor, leaf color and panicle load. At the end of each observation and evaluation, a conclusion was formulated with regard to the most limiting nutrient, which corresponded to the least performing treatment compared to the all nutrient treatment (T4).

Table 1. Upland soil and crop resources in Dandume Local Government Area

Village	Soil types as perceived by farmers	Soil types as identified by scientists	Major crops grown
Gyazama	*Turbaya*, sandy, white	Alfisol, sandy loam	Cassava, sweetpotato, rice, cowpea, sorghum, maize, soybean, cassava
	Jangarigari, clayey, red, sloppy area	Alfisol, clayey loam	Sorghum, millets, cotton
Mahuta	*Yarbuwa*, sandy, white	Alfisol, sandy loam	Sweetpotato, rice, cowpea, sorghum, maize, soybean, cassava
	Jangarigari, sandy, red, sloppy area	Alfisol, clayey loam	Sorghum, millets
Dansoda	*Jigawa*, sandy, white	Alfisol, sandy loam	Sorghum, maize, rice, cowpea, cocoyam, soybean
	Jangarigari, clayey, red, sloppy area	Alfisol, clayey loam	Sorghum, millets

Participatory evaluation of the nutrient-omission trial
Each participating farm was evaluated by groups of 3–4 farmers in the three villages. Nitrogen was the most limiting nutrient of upland rice yield on *Jigawa* soils in Dandume LGA (Table 2). Without fertilizer application and on no nitrogen plots (T1), plant height, crop vigor, leaf color and panicle load were seriously affected. Moreover, farmers observed that K was less limiting than N and P. They concluded that *Jigawa* soil required more N and P than K fertilizer.

Rice yields and nutrient deficiencies
The average paddy yields obtained across the 2 years ranged from 986 to 2323 kg/ha (Table 3). The lowest yields were given by the no fertilizer and no nitrogen treatments (T0 and T1) . This confirms that nitrogen is the most limiting nutrient for rice production in Dandume LGA, as also observed by farmers themselves. The second most limiting nutrient following N is P. T2 (no P) gave arithmetically lower yields across the sites compared to T4, meaning that P also limits paddy yield; however, this difference is not statistically significant. Potassium was clearing not limiting for paddy yield: T3 (no K) gave the best yields across the sites, often at least as high as T4. The potential supply of K from the soil is high. Without K fertilizer application on *Jigawa* soils, a minimum of 2 t/ha paddy yield was achievable when enough N and P were applied.

Table 2. Crop performance evaluation by farmers

Village	Soil type	Treatment		Crop performance†					
				Plant height	Crop vigor	Leaf color	Panicle load	Mean	Rank
Gyazama	*Jigawa*	T0	C	0.7	0.7	0.4	0.4	0.6	5
		T1	PK (no N)	1.7	2.3	1.6	1.4	1.8	4
		T2	NK (no P)	4.6	4.7	4.7	5.0	4.8	3
		T3	NP (no K)	6.4	6.3	6.4	6.4	6.4	2
		T4	NPK	6.6	6.0	6.9	6.7	6.5	1
Mahuta	*Jigawa*	T0	C	1.1	1.1	1.1	1.1	1.1	5
		T1	PK (no N)	3.2	3.2	2.9	3.0	3.1	4
		T2	NK (no P)	4.0	4.1	4.2	4.3	4.2	3
		T3	NP (no K)	4.5	4.5	4.6	4.6	4.6	2
		T4	NPK	7.3	7.1	7.2	7.0	7.2	1
Dansoda	*Jigawa*	T0	C	0.8	1.5	1.2	0.8	1.1	5
		T1	PK (no N)	1.6	2.2	2.4	2.2	2.1	4
		T2	NK (no P)	5.2	5.2	6.0	5.6	5.5	2
		T3	NP (no K)	6.8	6.6	6.4	6.0	6.5	1
		T4	NPK	5.8	5.2	4.0	5.4	5.1	3
Mean		T0	C	*0.9*	*1.1*	*0.9*	*0.8*	*0.9*	*5*
		T1	PK (no N)	*2.2*	*2.6*	*2.3*	*2.2*	*2.3*	*4*
		T2	NK (no P)	*4.6*	*4.7*	*5.0*	*5.0*	*4.8*	*3*
		T3	NP (no K)	*5.9*	*5.8*	*5.8*	*5.7*	*5.8*	*2*
		T4	NPK	*6.6*	*6.1*	*6.0*	*6.4*	*6.3*	*1*

† mark out of 20.
C, control.

Table 3. Average paddy yields across 2008 and 2009 cropping seasons

Treatment		2008	2009					
		Gyazama	Gyazama		Dansoda		Mahuta	
T0	(no fertilizer)	1174.6	986.1	c	974.5	c	1144.4	b
T1	(no N)	1591.7	1350.7	bc	1314.8	bc	1536.1	ab
T2	(no P)	1960.5	1694.4	ab	1893.5	ab	1555.6	ab
T3	(no K)	2322.5	2163.2	a	2115.8	a	1733.3	a
T4	(N+P+K)	2255.8	1822.9	ab	2125.0	a	1816.7	a
			$F(4,35)=3.71$; $P<0.0127$		$F(4,25)=4.99$; $P<0.0043$		$F(4,45)=3.24$; $P<0.0204$	

Yield with different letters are statistically different while the ones with same letter are statistically similar.

Site-specific fertilizer recommendation and validation

Crop response to recommended options

On *Jigawa* soil (Table 4), the response of the crop varied from one treatment to another. All recommended options, including the blanket one (V1), gave a better performance than the farmers' practices in all villages. However, when a rate of fertilizer was applied by the farmer, paddy yield was improved but not by as much as the recommended rates. The highest response of paddy yields to the recommended options compared to farmers' practices were obtained with V5 in Gyazama, Mahuta and Albasu (95%, 374% and 48.5% increases, respectively), and V4 in Dansoda (162% increase). The added effects of K fertilizers were low in Gyazama, Albasu and Dansoda (AE K: 0–13.4%), while a high added effect was recorded in Mahuta (AE K: 81.8%). The application of K fertilizers was not significantly effective on *Jigawa* soils in Gyazama, Albasu and Dansoda, but was in Mahuta.

On *Jangarigari* soil (Table 5), lower yields were obtained and the most effective treatment was the generalized recommendation (V1). Also, there was a moderate effect of added K fertilizer (AE K of 0 and 43.5% for V3 and V5, respectively). All nutrients seemed to be missing from this soil type.

Table 4. Crop response and profitability of recommended options on *Jigawa* soils per village

Village	Soil	Treatment					Yi	HI	RR	AE K	Po	Sup	FC	GM	RI	VCR
				N	P	K	(kg/ha)		(%)	(%)	(naira/kg)	Rev (naira)	(naira)	(naira)		
Gyazama	*Jigawa*	V0	FP	30.5	3.3	6.3	1667	0.18			50		29 640	53 693	1.8	
		V1	4NPK+2urea	76.0	13.1	25.0	3000	0.25	80.0		50	66 667	24 000	126 000	5.3	2.8
		V2	4urea+2TSP	92.0	20.1	0.0	1917	0.26	15.0		50	12 500	25 600	70 233	2.7	0.5
		V3	4urea+2TSP+1MOP	92.0	20.1	25.0	2033	0.28	22.0	*6.1*	50	18 333	31 600	70 067	2.2	0.6
		V4	3DAP+3urea	96.0	30.1	0.0	2867	0.28	72.0		50	60 000	28 950	114 383	4.0	2.1
		V5	3DAP+3urea+1MOP	96.0	30.1	25.0	3250	0.26	95.0	*13.4*	50	79 167	34 950	127 550	3.6	2.3
Mahuta	*Jigawa*	V0	FP	0	0	0	633	0.16			50			31 667		
		V1	4NPK+2urea	76.0	13.1	25.0	1833	0.37	189.5		50	60 000	24 000	67 667	2.8	2.5
		V2	4urea+2TSP	92.0	20.1	0.0	1967	0.21	210.5		50	66 667	25 600	72 733	2.8	2.6
		V3	4urea+2TSP+1MOP	92.0	20.1	25.0	2100	0.22	231.6	*6.8*	50	73 333	31 600	73 400	2.3	2.3
		V4	3DAP+3urea	96.0	30.1	0.0	1650	0.17	160.5		50	50 833	28 950	53 550	1.8	1.8
		V5	3DAP+3urea+1MOP	96.0	30.1	25.0	3000	0.24	373.7	*81.8*	50	118 333	34 950	115 050	3.3	3.4
Albasu	*Jigawa*	V0	FP	30.5	3.3	6.3	1667	0.21			50		29 640	53 693	1.8	
		V1	4NPK+2urea	76.0	13.1	25.0	2042	0.20	22.5		50	18 750	24 000	78 083	3.3	0.8
		V2	4urea+2TSP	92.0	20.1	0.0	2108	0.16	26.5		50	22 083	25 600	79 817	3.1	0.9
		V3	4urea+2TSP+1MOP	92.0	20.1	25.0	2133	0.23	28.0	*1.2*	50	23 333	31 600	75 067	2.4	0.7
		V4	3DAP+3urea	96.0	30.1	0.0	2342	0.17	40.5		50	33 750	28 950	88 133	3.0	1.2
		V5	3DAP+3urea+1MOP	96.0	30.1	25.0	2475	0.18	48.5	*5.7*	50	40 417	34 950	88 800	2.5	1.2
Dansoda	*Jigawa*	V0	FP	0	0	0	700	0.27			50			35 000		
		V1	4NPK+2urea	76.0	13.1	25.0	1817	0.37	159.5		50	55 833	24 000	66 833	2.8	2.3
		V2	4urea+2TSP	92.0	20.1	0.0	1400	0.21	100.0		50	35 000	25 600	44 400	1.7	1.4
		V3	4urea+2TSP+1MOP	92.0	20.1	25.0	1567	0.22	123.8	*11.9*	50	43 333	31 600	46 733	1.5	1.4
		V4	3DAP+3urea	96.0	30.1	0.0	1833	0.17	161.9		50	56 667	28 950	62 717	2.2	2.0
		V5	3DAP+3urea+1MOP	96.0	30.1	25.0	1433	0.23	104.8	*–21.8*	50	36 667	34 950	36 717	1.1	1.0
Average	*Jigawa*	*V0*	*FP*	*FP*	*FP*	*FP*	*946*	*0.18*			*50*		*29 640*	*17 652*	*0.6*	
		V1	*4NPK+2urea*	*76.0*	*13.1*	*25.0*	*2113*	*0.28*	*123.3*		*50*	*58 333*	*24 000*	*81 625*	*3.4*	*2.4*
		V2	*4urea+2TSP*	*92.0*	*20.1*	*0.0*	*1596*	*0.21*	*68.7*		*50*	*32 500*	*25 600*	*54 192*	*2.1*	*1.3*
		V3	*4urea+2TSP+1MOP*	*92.0*	*20.1*	*25.0*	*1700*	*0.23*	*79.7*	*6.5*	*50*	*37 708*	*31 600*	*53 400*	*1.7*	*1.2*
		V4	*3DAP+3urea*	*96.0*	*30.1*	*0.0*	*1846*	*0.19*	*95.2*		*50*	*45 000*	*28 950*	*63 342*	*2.2*	*1.6*
		V5	*3DAP+3urea+1MOP*	*96.0*	*30.1*	*25.0*	*2292*	*0.24*	*142.3*	*24.2*	*50*	*67 292*	*34 950*	*79 633*	*2.3*	*1.9*

Yi, paddy yield; HI, harvest index ; RR, relative response; AE, added effects [of K]; Po, average market grain price; Sup Rev, supplementary revenue; FC, cost of fertilizer; GM, gross margin; RI, return on investment; VCR, value–cost ratio; FP, farmer’s practice; TSP, triple super phosphate; MOP, muriate of potash; DAP, diammonium phosphate.

Table 5. Crop response and profitability of recommended options on *Jangarigari* soil

Village	**Soil**	**Treatment**					**Yi (kg/ha)**	**HI**	**RR (%)**	**AE K (%)**	**Po (naira/kg)**	**Sup Rev (naira)**	**FC (naira)**	**GM (naira)**	**RI**	**VCR**
				N	**P**	**K**										
Dandume	Janga	V0	FP	FP	FP	FP	783	0.14			50.0		29 640	9 527	0.3	
	Rigari	V1	4NPK+2urea	76.0	13.1	25.0	1800	0.21	129.8		50.0	50 833	24 000	66 000	2.8	2.1
		V2	4urea+2TSP	92.0	20.1	0.0	1100	0.15	40.4		50.0	15 833	25 600	29 400	1.1	0.6
		V3	4urea+2TSP+1MOP	92.0	20.1	25.0	1100	0.18	40.4	0.0	50.0	15 833	31 600	23 400	0.7	0.5
		V4	3DAP+3urea	96.0	30.1	0.0	1033	0.15	31.9		50.0	12 500	28 950	22 717	0.8	0.4
		V5	3DAP+3urea+1MOP	96.0	30.1	25.0	1483	0.23	89.4	43.5	50.0	35 000	34 950	39 217	1.1	1.0

For abbreviations, see Table 4.

Economic evaluation of the recommended options

The nutrient-omission trial-based recommendations provided the best performance in Mahuta and Albasu villages on *Jigawa* soil, V5 giving the most profitable option (Table 4): a value–cost ratio (VCR) of 3.4 for fertilizer input, a return on investment (RI) of 3.3 and a gross margin (GM) of 115 050 naira in Mahuta, followed by V2, a cheaper option. In Albasu, V5 and V4 gave the highest GM (> 88 000 naira) and VCR (1.2), while V1 and V2 returned more revenue (> 3 naira per naira invested). However, the additional revenues of V1 and V2 were not sufficient to be invested the following year in rice production with the same quantity of fertilizer used the previous year. V5 still gave more supplementary income (Sup Rev of 79 167 naira and GM of 127 550 naira) in Gyazama, but the generalized recommendation (V1) was more competitive, giving the highest VCR of 2.8, RI of 5.3 and a GM as high as for V5 (126 000 naira). V1 also performed better in Dansoda, with VCR of 2.3, RI of 2.8 and GM of 66 833 naira.

On *Jangarigari* soil in Dandume (Table 5), V1 performed best: VCR (2.1), RI (2.8) and GM (66 000 naira).

Public awareness

Several farmers' field days and exchange visits where organized, where other farmers from the pilot and neighboring villages, village heads, local government authorities, input dealers, and media were invited to share with the participating farmers and researchers the outputs of this process. At these events, participating farmers were able to explain the objective, process and outputs of their activities in the framework of this project.

Discussion

More used for upland rice production in Dandume LGA, *Jigawa* soil is more productive than *Jangarigari*. Clayey and less fertile, *Jangarigari* does not facilitate water infiltration and is difficult to manage during dry spells, which are frequent in this area. *Jigawa* promotes water infiltration and rice root development. *Jangarigari* occurs on more sloppy areas. Its topsoil is eroded by wind and water. Hence, farmers do not like growing rice on Jangarigari soils, but rather on *Jigawa*. This participatory nutrient-omission trial contributed to bringing farmers and researchers to the same conclusion that nitrogen and phosphorus limit upland rice paddy yields more than potassium on *Jigawa*. These results confirm earlier research in the NGS (Adejobi and Kormawa, 2002). However, the essence of this study was not to challenge the former research outputs, but to facilitate the understanding of the principles behind fertilizer recommendations by farmers so that they can easily adopt fertilizer use and accommodate it into their reality. They participated in the diagnosis of soil fertility and implemented the observations and evaluations and come to the same conclusions as the scientists. They have become more familiar with mineral fertilizers and their roles in rice production.

The validation test showed that a blanket recommendation does not always perform best across an agro-ecological zone. Emphasizing nitrogen and phosphorus fertilizers (V2 and V4) improved rice yields in all the pilot villages. However, a slight yield increase was obtained with the addition of K fertilizer (0–13.4%) in Gyazama, Albasu and Dansoda, but a higher added effect of 81.8% was obtained in Mahuta. After supplying enough N and P to the soil by mineral fertilizers, K becomes more limiting. N and P fertilizer recommendation helped close the gap between the NGS average paddy yield of 700 kg/ha and the national average of 1.5 t/ha on *Jigawa* soils using NERICA 1 improved variety.

The farmers have now more flexible options, being aware of the most limiting nutrients of the soil and the methodology to determine them. Their capacity to make decisions on what type of fertilizer is more needed when they have limited financial resources has been strengthened.

When high paddy yields are targeted on *Jigawa* soil, V5 (3 DAP + 3 urea + 1 MOP) is the best option for farmers in Gyazama, Mahuta and Albasu (95%, 374% and 48.5% increases, respectively), and V4 (3 DAP + 3 urea) is the best in Dansoda (162% increase). The highest yields were given by V1 (4 NPK + 2 urea) only on *Jangarigari* soil.

On an economic basis, V5 (3 DAP + 3 urea + 1 MOP) was more profitable on *Jigawa* soil in Mahuta and Albasu, while V1 (4 NPK + 2 urea) was the best option in Gyazama and Dansoda. V1 (4 NPK + 2 urea) seemed to be the best option on *Jangarigari* soil in Dandume village.

So, it is clear that even if K is not the most limiting nutrient for upland rice production in the study area, it is important to apply it to achieve high target yields. For the sustainability of the production system, it is good to apply at least 1 bag of MOP every 2 years and return all rice straw to the soil if a paddy yield of 2 t/ha is targeted, and systematically apply the recommended options (V5 in Mahuta and Albasu, and V1 in Dansoda and Gyazama and on *Jangarigari* soil in Dandume village) if a yield higher than 2 t/ha is targeted. These are site-specific options that could be revisited every 5 years in order to maintain good yields. Integrating legumes like soybean or cowpea in the system by strip cropping or rotation (Kolawole *et al.*, 2007) on V5 plots could be profitable for the farmers, because of the residual effect of phosphorus contained in DAP fertilizer. The cow dung application commonly practiced by farmers in the area has to be encouraged to increase the nutrient use efficiency of the applied mineral fertilizers in order to limit nutrient leaching, and hence environmental pollution.

Acknowledgements

The authors are grateful for the funding of this study from the Forum for Agricultural Research in Africa, through the KKM (Kano–Katsina–Maradi) Project of the Sub-Saharan Africa Challenge Programme. They also express their recognition to the important roles played by all the stakeholders, including IFDC (lead institute of the Northern Guinea Savannah of KKM Project), National Agricultural Extension Research Liaison Services, Institute for Agricultural Research, Dandume Local Government, Katsina State Agricultural and Rural Development Authority (extension service), and especially the farmers, for the achievement of the goal of this study.

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