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Full Length Research Paper

Effect of crop rotation and nitrogen fertilization on yield and nitrogen efficiency in maize in the northern Guinea savanna of Nigeria

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Two crop rotation cycles were evaluated to determine the effect of cropping systems and N fertilization on the yield and efficiency of N in maize. Maize was grown on plots which had previously supported monocrops of two genotypes each of soybean (TGx 1448-2E and SAMSOY-2) and cowpea (IT 96D-724 and SAMPEA-7), natural fallow and maize. In a split-plot experimental design, three N fertilizer rates (30, 60 and 90 kg ha^{-1}) and an unfertilized control were compared. On average, maize following legumes had higher grain yield of 1.2 and 1.3-fold compared with maize after fallow or maize after maize respectively. Similarly, legume rotation resulted in significant increase in total N uptake compared to continuous maize. In both years, N agronomic efficiency (AE_N) and N fertilizer recovery efficiency (RE_N) of maize following grain legumes were on average 14 and 34% greater than of maize following maize and 12 and 20% greater than of maize following fallow respectively. On the other hand, all N efficiency indices except N physiological efficiency significantly decreased with increasing N levels. These indicate greater N use efficiency for the legume- rotation and poor efficiency for maize monoculture as well as the inefficiency of the current method of N fertilizer application.

Key words: Fallow, grain legumes, maize, N uptake, N use efficiency, N fertilizer recovery efficiency.

INTRODUCTION

Nitrogen (N) is the most important mineral nutrient limiting maize (*Zea mays* L) production in the Nigerian savanna (Uyovbisere et al., 1997; Carsky and Iwuafor, 1999; Sanginga et al., 2001; Yusuf et al., 2003). Despite its low inherent supply in the soil, N deficiency is further exacerbated from its continual depletion from the soil pool by removal of N-containing crop residues from the farm. Nitrogen depletion in maize-based systems in some farmers' fields in West African savanna is estimated to be 36 - 80 kg N ha^{-1} per year (Sanginga et al., 2001) and it has been obvious since the mid 1990s that fertilizer use is necessary if sustainable agricultural production in smallholder farms is to be raised to levels that can sustain the growing population. However, mineral fertilizers are too expensive beyond the reach of the resource poor farmers. In most cases, quantities lower than the recommended rates are applied and this could lead to reduction in crop yield and profit. The current less than 20 kg nutrient ha^{-1} fertilizer use in Nigeria was considered grossly inadequate and 50 kg nutrient ha^{-1} fertilizer use was recommended across sub-Saharan Africa by African heads of states at the Fertilizer Summit held in 2006 at Abuja, Nigeria. Therefore, research is required to increase judicious use of fertilizer and develop sustainable management practices in response to continually increasing economic and environmental pressures.

Grain legumes are good source of food, fodder and cash for the farmer as well as excellent components within the various farming systems because they provide residual N and reduce the needs for mineral N fertilizers by associa-

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ted non-legumes. Depending on the legume variety, net soil N accrual from the incorporation of grain legume residue can be as much as 140 kg N ha^{-1} if only seeds are harvested (Giller, 2001). Crop rotation with legumes improves soil physical, chemical and biological conditions (Chan and Heenan, 1996; Bagayoko et al., 2000; Giller, 2001; Yusuf et al., 2009a), thereby enhancing soil nutrient availability (Loewy, 1987) . Crop rotation significantly influences N use efficiency and prompts changes in various N sources, affecting availability to the plant (L pez-Bellido and L pez-Bellido, 2001) . Some authors studying particular N efficiency indices concluded that efficiency is greater in rotation than in monoculture (Badaruddin and Meyer, 1994; Yamoah et al., 1998; Soon et al., 2001). This view was supported by Dawson et al. (2008) in their review of over 100 literatures on this subject matter. This could be related to a greater degree of synchronization between crop N-extraction and the N dynamic in rotation than in monoculture (Pierce and Rice, 1988).

Integration of legumes into the cropping systems of the northern Guinea savanna of Nigeria (NGSN) has been considered as an important resource management technology for reduction of energy use, cost and pollution potential of inorganic fertilizer usage (Yusuf et al., 2009b). However, crop rotation with legumes alone can-not supply all the N requirements by the non- legume component of the maize-based cropping system. This is because the current practice of exporting all above ground biomass at harvest largely contribute to negative soil N balance (Sanginga et al., 2002). Supplementary N fertilizer would therefore be necessary to obtain higher yield. However, N fertilizer management may not be uniform under different cropping systems. Some studies have suggested that varying the timing of N fertilizer application to cereal in monoculture and in rotation could lead to increased yield, N use efficiency and N uptake efficiency (L pez-Bellido et al., 1996). Very few studies have been conducted to evaluate the N use efficiency of cropping systems in the NGSN (Carsky et al., 1999) and no information is available on the efficiency of the current method of fertilizer application to maize in different cropping systems. Irrespective of the previous culture in the rotation, the recommended practice is two split applications. Half of the recommended rate (60 kg N ha^{-1}) is applied at two weeks after planting (WAP) and the remaining half is applied at the beginning of stem elongation (six WAP) (FFD, 2002). In addition to timing of application of fertilizer N, amount and temporal distribution of rainfall also have a large influence on yield potential. Maize may not respond to fertilizer N under very dry or wet conditions. Hence the interaction of climate and management causes tremendous year-to-year variation in yields and crop N requirements (Montemurro et al., 2006). In the last decade, annual rainfall amount and distribution has been erratic in the NGSN (Oluwasemire and Alabi, 2004). Therefore the objective of this study was to evaluate the effect of crop rotation and N fertilisation on the yield and efficiency of nitrogen in maize in a changing climate.

MATERIALS AND METHODS

Experimental site

The field experiments were conducted from 2003 - 2005 at Samaru. Samaru is located in the northern Guinea savanna (NGS) of Nigeria (11°11'N and 7°38'E) and has a monomodal rainfall pattern with eighty years mean annual rainfall of 1011 ± 161 mm concentrated almost entirely in the five months (May/June - September/October) of the cropping season (Oluwasemire and Alabi, 2004). The main soil sub-group is Typic Haplustalf (Awujoola, 1979) or Chromic cambisols according to the FAO system of soil classification (FAO, 2001). Rainfall data during the period of the experiment was obtained from the weather station of the Institute for Agricultural Research, Samaru located about 500 m away from the experimental field.

Field experiment

The field experiment established to study the rotation effects of grain legumes and fallow on subsequent maize included two genotypes each of cowpea (SAMPLE-7 and IT 96D-724), soybean (SAMSOY-2 and TGx 1448-2E) and a natural bush fallow. A natural bush fallow (2 year old) was included to emulate farmers' traditional method of soil fertility maintenance. The experimental plots except the fallow were ploughed and ridged at an inter-row distance of 75 cm. The field was divided into two equal halves to accommodate two rotation cycles within three years. The first cycle of the rotation was initiated on the first half of the field in 2003 and completed in 2004 while the second rotation cycle was initiated on the second half of the field in 2004 and completed in 2005. In the first phase of each cycle, legumes (cowpea and soybean) and a hybrid maize, Oba super 2 (cv. 8644 - 27) were planted as the main crops. Each plot size measured 24.0 x 4.5 m (six rows). A basal application of 20 kg N as urea (46% N), 17.5 kg P as single super phosphate (18% P_2O_5) and 16.7 kg K as muriate of potash (60% K_2O) per hectare was made to soybean and cowpea plots. A 'starter dose' of nitrogen is required in the Nigerian savanna to eliminate constraints due to low soil fertility that may hamper initiation of nodules and onset of N_2 fixation since legume inoculants are not currently used by farmers. In the second phase of each rotation cycle, only maize was planted on all plots including the fallow plots. The experimental design was a split plot in the second phase of each rotation cycle. The main plots were the previous legume genotypes, fallow and maize while the sub plots (6.0 x 4.5 m) were three rates of fertilizer N; 30, 60 and 90 kg N ha^{-1} and an unfertilized control plot. Maize seeds were planted manually on 16th June 2004 and 14th June 2005 using three seeds per hill at 25 cm between plants and 75 cm between rows. The seedlings were thinned to one plant per hill 2 weeks after planting (WAP) to obtain a plant density of 53, 333 plants per hectare. The N fertilizers were applied in two splits, one-half was applied at two WAP and the remaining one-half was applied at 6 WAP. The fertilizer was applied by spot application in a hole made about 5 cm away from the plant stands and covered. Phosphorus (26.2 kg P ha^{-1}) and K (50 kg K ha^{-1}) fertilizers were applied to all plots at planting by side banding at about 5 cm away from the seed and at about 5 cm deep on the ridge.

Soil sampling and analysis

For initial characterization of the field, twenty core (8 cm in diameter) soil samples (0 - 15 cm depth) were taken at random along four transects in the field. The samples were thoroughly mixed and bulked, and a representative sample was drawn for initial chemical analysis following standard procedures (IITA, 1989). The soil was loam in texture with the following properties: pH (Water), 5.4; C_{org}, 6.3 g kg^{-1}; N_{tot}, 0.50 g kg^{-1}; available P (Bray 1-P), 6.53 mg kg^{-1}; and exchangeable cations ($cmol_+$ kg^{-1}) of Mg^{2+}, 0.36; Ca^{2+}, 0.80; K^+, 0.15; and Na^+, 0.28.

Plant sampling and analysis

Plant sampling was done at 50% silking for maize and at maturity. Five plant samples were taken from the maize plot by cutting at the base of the stem. Harvested plant samples were chopped into 10 - 20 mm pieces and sub sampled, and about 500 g fresh weight were oven-dried at 70°C before grinding to pass through a 0.5 mm sieve. For the last harvest, plant samples were separated into reproductive (grains) and vegetative parts (shoots) before sampling. The grains were threshed from the pods and cobs and further dried in the sun until a moisture content of 12% was reached using a Dickey-john grain moisture tester. Maize straws were dried in the oven at 70°C to a constant weight before weighing. Total N in the grains and straws was determined by the Kjedahl procedure (Bremner and Mulvaney, 1982).

Nitrogen efficiency parameters

The following N-efficiency parameters were calculated for each treatment following Cassman et al., 1998; L pez-Bellido and L pez-Bellido, 2001.

1.) N agronomic efficiency (AEN; kg kg-1) as the ratio of (yield at Nx –yield at N0) to applied N at Nx.
2.) N physiological efficiency (PEN; kg kg-1) as the ratio of (yield at Nx – yield at N0) to (N uptake at Nx – N uptake at N0).
3.) N fertilizer recovery efficiency (REN; %) as the ratio of (N uptake at Nx – N uptake at N0) to applied N at Nx.

Statistical analysis

Data collected for each parameter were subjected to analysis of variance (ANOVA) using the STATISTICA program 2007 (StatSoft Inc., Tulsa, OK, USA). Where the F-ratios were found to be significant, treatment means were separated using the Fisher's least significant difference (LSD) at P 0.05 (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Amount and distribution of rainfall

Rainfall data collected during the period of the experiment are presented in Figure 1. The total rainfall was higher in 2003 (1118 mm) followed by 2004 (1109 mm) and the least amount recorded in 2005 (887 mm). The rain started earlier in March of 2003 and 2004 compared to 2005 but it was followed by a period of long drought in 2004 (Fig. 1). The total rainfall in 2005 was below the long- term mean but it was uniformly distributed such that crop yields were not adversely affected.

Grain yield

A significant year effect occurred for grain yield of maize in 2004 and 2005; therefore, data are presented by year (Table 1). A mean value of 2326 (2004) and 2512 kg ha^{-1} (2005) were obtained (Table 2). The higher grain yield in 2005 could be due to favourable soil moisture at planting and good distribution of rainfall until harvest. The total rainfall before planting in 2005 was 203.7 mm or 23% of the total while 134.9 mm or 13% of the total rainfall was obtained at planting in 2004. Favourable moisture regime in the soil is essential for good crop establishment, which affects yield.

In 2004, no differences were recorded between legume-maize rotations but all rotations differed significantly from continuous maize and maize following fallow while in 2005, grain yield of maize following soybean genotypes was significantly higher than following cowpea genotype, IT 96D-724, fallow-maize and continuous maize (Table 2) . Maize following cowpea genotype, SAMPEA-7 also gave significantly higher yield than maize following and continuous maize. No significant difference was observed in maize yield following IT 96D-724 and following fallow but continuous maize was statistically inferior to all legume rotations. It seems therefore that the narrowing of the difference in yields from the various legume rotations in 2004 may be due to the fact that water has ceased to be a limiting factor, although in this case excessive rainfall (883.7 mm; 87% of total rainfall) after planting may also limit maize growth on Alfisols. In general, rotation with grain legumes provided higher yields than maize after fallow and continuous maize. Several other workers have reported improved maize yield after a crop of legume in the same agro-ecological zone (Kaleem, 1993; Carsky et al., 1997, 1999; Sanginga et al., 2002) (Table 1). A mean value of 2326 (2004) and 2512 kg ha^{-1} (2005) were obtained (Table 2). The higher grain yield in 2005 could be due to favourable soil moisture at planting and good distribution of rainfall until harvest. The total rainfall before planting in 2005 was 203.7 mm or 23% of the total while 134.9 mm or 13% of the total rainfall was obtained at planting in 2004. Favourable moisture regime in the soil is essential for good crop establishment, which affects yield.

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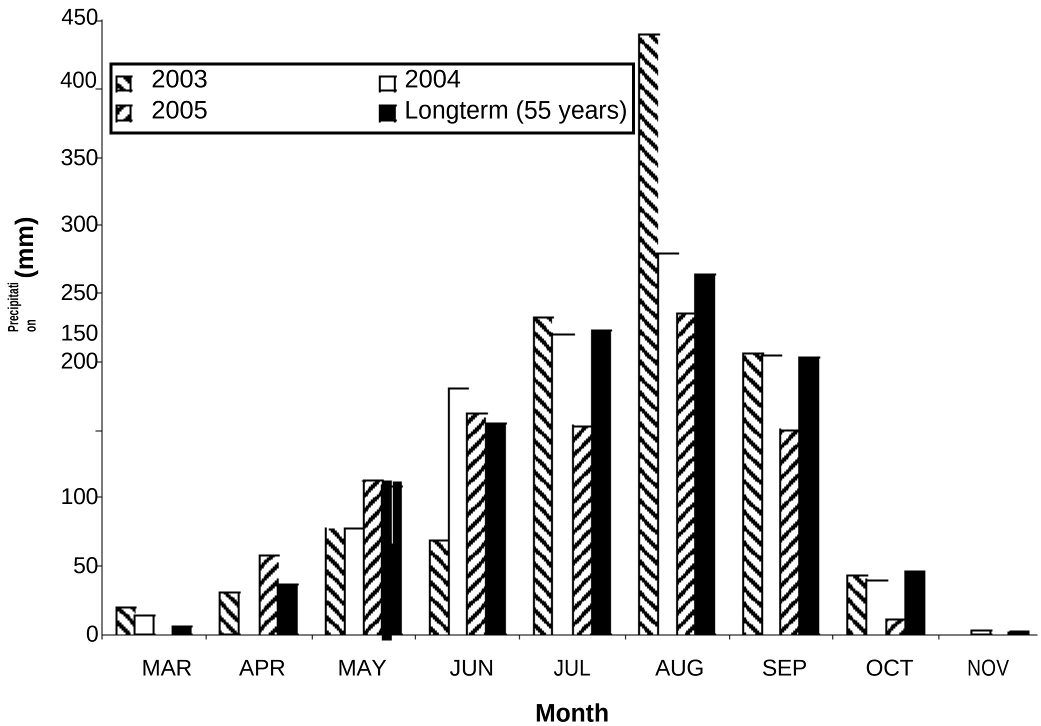

Figure 1. Monthly annual precipitation for three years (2003, 2004 and 2005) at Samaru.

Table 1. The F ratios of analyses of variance of grain yield, N uptake, N agronomic efficiency (AE_N), N physiological efficiency (PE_N) and N fertilizer recovery efficiency (RE_N) for maize in a rotation-N rate trial in Samaru (Nigeria).

Source	d.f.	Grain yield	N uptake	d.f.	AE_N	PE_N	RE_N
Year (Yr)	1	7.88**	3.24	1	0.52	0.98	8.18***
Prev. Crop (PC)	5	14.34***	10.30***	5	6.34***	1.33	9.17***
N rate (N)	3	162.25***	125.02***	2	5.77**	10.27***	125.34***
PC x Yr	5	0.59	0.62	5	1.18	0.96	0.29
PC x N	15	1.03	0.81	10	1.40	1.41	2.97
Yr x N	3	1.46	0.95	2	1.60	1.00	1.26
PC x Yr x N	15	0.44	0.79	10	1.00	1.35	0.51

** Significant at P 0.01
*** Significant at P 0.001

be due to the fact that water has ceased to be a limiting factor, although in this case excessive rainfall (883.7 mm; 87% of total rainfall) after planting may also limit maize growth on Alfisols. In general, rotation with grain legumes provided higher yields than maize after fallow and continuous maize. Several other workers have reported improved maize yield after a crop of legume in the same agro-ecological zone (Kaleem, 1993; Carsky et al., 1997, 1999; Sanginga et al., 2002)(Table 1). A mean value of 2326 (2004) and 2512 kg ha^{-1} (2005) were obtained (Table 2). The higher grain yield in 2005 could be due to favourable soil moisture at planting and good distribution of rainfall until harvest. The total rainfall before planting in 2005 was 203.7 mm or 23% of the total while 134.9 mm or 13% of the total rainfall was obtained at planting in 2004. Favourable moisture regime in the soil is essential for good crop establishment, which affects yield.

In 2004, no differences were recorded between legume-maize rotations but all rotations differed significantly from continuous maize and maize following fallow while in 2005, grain yield of maize following soybean genotypes was significantly higher than following cowpea genotype, IT 96D-724, fallow-maize and continuous maize (Table 2). Maize following cowpea genotype,

Table 2. Maize grain yield (kg ha^{-1}) and maize N uptake (kg ha^{-1}) as affected by crop rotation and rate in a rotation-N rate trial in Samaru (Nigeria).

Treatment	Year[a]				Mean[a]	
	2004		2005			
	Grain yield	N uptake	Grain yield	N uptake	Grain yield	N uptake
	(kg ha^{-1})		(kg ha^{-1})		(kg ha^{-1})	
Previous Crop						
Fallow	2020b	61c	2028c	61d	2099c	61d
Maize	1960b	62c	1990c	66cd	2008c	61d
TGx 1448-2E	2503a	75ab	2633ab	84ab	2680a	80ab
SAMSOY-2	2595a	79a	2902a	88a	2761a	83a
SAMPEA-7	2505a	75ab	2606b	75bc	2555ab	75bc
IT96D-724	2373a	67bc	2448b	70bcd	2410b	68cd
N rate (kg ha^{-1})						
0	1389d	40d	1373d	40c	1384d	40d
30	1995c	60c	2208c	70b	2126c	65c
60	2668b	83b	2844b	88a	2848b	86b
90	3252a	97a	3312a	98a	3318a	97a
Mean	2326B	70A	2512A	74A		

[a]Within year and treatment (previous crop, or N rate) means followed by the same letter are not significantly different at P 0.05 according to Fisher's LSD.

SAMPEA-7 also gave significantly higher yield than maize following and continuous maize. No significant difference was observed in maize yield following IT 96D-724 and following fallow but continuous maize was statistically inferior to all legume rotations. It seems therefore that the narrowing of the difference in yields from the various legume rotations in 2004 may be due to the fact that water has ceased to be a limiting factor, although in this case excessive rainfall (883.7 mm; 87% of total rainfall) after planting may also limit maize growth on Alfisols. In general, rotation with grain legumes provided higher yields than maize after fallow and continuous maize. Several other workers have reported improved maize yield after a crop of legume in the same agro-ecological zone (Kaleem, 1993; Carsky et al., 1997, 1999; Sanginga et al., 2002).

In both years, irrespective of the previous crop, maize grain yield significantly increased with increasing N application (Table 2). Each N rate produced grain yield that was significantly different from the other with the highest grain yield of 3252 kg ha^{-1} at 90 kg N ha^{-1} in 2004. Similar observation was made in 2005 with the highest grain yield (3312 kg ha^{-1}) obtained at 90 kg N ha^{-1} and the lowest at 0 kg N ha^{-1}. The grain yields obtained with the application of 60 kg N ha^{-1} were significantly higher than the values recorded at 30 kg N ha^{-1} in both years. Response to N application in NGSN has been documented by several authors (Uyovbisere et al., 1997; Carsky and Iwuafor, 1999; Sanginga et al., 2001; Yusuf et al., 2003).

The interaction between previous crop and fertilizer N (P x N) was not significant in both years (P = 0.94 in 2004 and P = 0.57 in 2005). This indicates that N–effect might not have been solely responsible for the results obtained on maize grain yield. Improvements in other soil physical, chemical and other biological conditions were found to be associated with these yield increases (Chan and Heenan, 1996; Bagayoko et al., 2000; Giller 2001; Yusuf et al., 2009a).

Nitrogen uptake

Total N uptake in succeeding maize differed significantly between crop rotations and N fertilizer rates. Although year had no significant effect on total N uptake (Table 1), it was proportional to yield with a higher mean of 74 kg ha^{-1} in 2005 than 70 kg ha^{-1} in 2004 (Table 2). These values are low and could be responsible for the low grain yield in both years. Where N is the most limiting nutrient, its uptake has tremendous influence on grain yield. Montemurro et al. (2006) reported a mean total N uptake of 241 kg N ha^{-1} to obtain maize grain yield of 8,200 kg ha^{-1} under Mediterranean conditions.

Crop rotation significantly influenced total N uptake over the entire study period, being significantly lower in fallow-maize and continuous maize systems than in any of the rotation consistent with lower grain yield. Diversity and quality of crop residues in the legume-maize rotation could be responsible for higher N uptake compared to other systems. Though less in residue input to soils than cereals and other crops, below ground residues of soybean and other pulses have been reported to support more microbial population which influences the concentrations of nutrients released in the rhizosphere for plant uptake (Balota et al., 2003). Among the legume rotations, maize following SAMSOY- 2 had the highest uptake while IT 96D-724-maize rotation was the lowest.

Increasing N fertilizer rates prompted significant increase in total N uptake (Table 2). The values were similar in both years, rising as fertilizer rates increased. The trend was similar to the already reported response of grain yield to N fertilizer rates, for which significant differences were recorded at each N rate.

Nitrogen efficiency

Nitrogen agronomic efficiency: Nitrogen agronomic efficiency (AE_N) was significantly affected by crop rotation and N rate (Table 3). The trends were similar in both 2004 and 2005. On average, AE_N was significantly higher in legume-maize rotations than fallow-maize, which did not differ significantly from continuous maize. Among the legume rotations, maize following SAMSOY-2 had the highest AE_N, the lowest with maize following both cowpea genotypes and maize following TGx 1448- 2E occupying the intermediate position. The AE_N values matched well with the grain yield. The mean value of 27 kg_{grain} (kg $N_{fertilizer})^{-1}$ obtained in this study was lower than the value of 42 kg_{grain} (kg N $_{fertilizer})^{-1}$ and even much lower than 57 kg_{grain} (kg $N_{fertilizer})^{-1}$ reported in USA in 1980 and 2000 respectively (Frink et al., 1999). The difference could be due to improvement in the indigenous N supply from net mineralization of soil organic matter, atmospheric N inputs, and biological N_2 fixation (BNF) over the past two decades in USA. In contrast, we do not expect large contribution from BNF in our study due to removal of all legumes above ground biomass from the experimental plots as practiced by the farmers in the agro-ecological zone. Moreover, the soil organic matter content of our experimental field was very low (6.30 g kg^{-1}), which is representative of most Nigerian savanna soils were values are often less than 10 gkg^{-1} (Enwezor et al., 1988).

On average, AE_N declined with increasing N fertilizer rates, although no significant differences were observed between 30 and 60 kg N ha^{-1} (Table 2). This suggests greater losses of N from the system and points to the need for further research to match the time of fertilizer application with the period of high crop demand without excess or deficiency.

Nitrogen physiological efficiency: Nitrogen physiological efficiency (PE_N) was not significantly influenced by year and rotation systems but the effect of N rate was significant (Table 3). The effect of crop rotation did not mirror trends in grain yields (Table 2). The lack of significant difference in the change in grain yield per unit change in N accumulation in aboveground biomass could be attributed to the fact that this parameter is largely governed by genetic factors: i) mode of photosynthesis- either the C_3 or C_4 photosynthetic pathway; or ii) the grain N concentration. Nitrogen supply may as well affect PE_N. On average, increased N fertilizer rates resulted in an increase in PE $_N$, with the highest in 90 kg N ha^{-1} and the lowest with 30 kg N ha^{-1} (Table 3) . Our results match well with increasing plant N uptake as N supply increases and it suggests that higher grain yield could be achieved at higher N rate. When N is no longer the most limiting resource and other factors such as water supply, pest damage, or deficiencies of other nutrients control crop growth, PE_N is expected to decrease (Cassman et al., 2002).

Nitrogen fertilizer recovery efficiency: N fertilizer recovery efficiency (RE_N) was significantly influenced by year, crop rotation and N rate (Table 1) . In 2005, the year with the highest grain yield, the value recorded for RE_N was significantly higher than in 2004 (Table 3) . The higher values in 2005 could be due to higher grain yield, caused by although relatively low but good rainfall distribution. Cassman et al. (2002) reported large variability in RE_N for wheat in rice-wheat systems of India. The value was 18% in one year and 49% the next. This difference was associated with low grain yields in the first year caused by unfavorable weather, and highlights the importance of robust crop growth and yield to greater RE_N. Heavy rainfall, especially when concentrated shortly after fertilizer N application could result into low recovery in crops.

RE_N was significantly higher after legumes than after natural fallow or maize in both 2004 and 2005 (Table 3). Among the legume genotypes, it was significantly higher in maize following both soybean genotypes and SAMPEA-7 than maize followed by IT 96D-724. These were significantly higher than maize following fallow, which did not differ significantly from continuous maize. Several studies have reported higher RE_N values in rotation than in monoculture (Huang et al., 1996; L pez-Bellido and L pez-Bellido, 2001; Cassman, 2001). However, Carsky et al. (1999) reported lower RE_N values in maize following soybean genotype, (TGx 1660-19F) than maize following natural fallow in the NGSN. This could be due to genetic difference between the soybean cultivars and suggests that the large variation in biological nitrogen fixation (BNF) potential within each of the major grain legume species can be used to select cultivars with the ability to improve RE_N when grown in rotation with non legume crop.

Irrespective of the cropping system and N rate, the average RE_N value was 48% in 2004 and 54% in 2005 (Table 3). The high RE_N values obtained in this study compared with an average of 42% obtained in developed countries (Raun and Johnson, 1999) may have been influenced by improved agronomic practices such as

Table 3. N agronomic efficiency (AE_N), N physiological efficiency (PE_N) and N fertilizer recovery efficiency (RE_N) for maize in a rotation-N rate trial in Samaru (Nigeria).

Treatment	Year[a]								
	2004			2005			Mean[a]		
	AE_N	PE_N	RE_N (%)	AE_N	PE_N	RE_N (%)	AE_N	PE_N	RE_N (%)
	kg_{grain} $(kg\ N_{fertilizer})^{-1}$	kg_{grain} $(kg\ N_{uptake})^{-1}$	kg_{grain} $(kg\ N_{fertilizer})^{-1}$	kg_{grain} $(kg\ N_{fertilizer})^{-1}$	kg_{grain} $(kg\ N_{uptake})^{-1}$	kg_{grain} $(kg\ N_{fertilizer})^{-1}$	kg_{grain} $(kg\ N_{fertilizer})^{-1}$	kg_{grain} $(kg\ N_{uptake})^{-1}$	kg_{grain} $(kg\ N_{fertilizer})^{-1}$
Previous Crop									
Fallow	25.1c	31.7a	41.7b	25.5cd	30.1a	46.2bc	25.3c	30.9a	44.0c
Maize	25.5c	29.2a	40.2b	24.7d	29.2a	42.1c	25.1c	29.2a	41.1c
TGx 1448-2E	28.8ab	31.4a	52.8a	28.2abc	29.6a	59.8a	28.5ab	30.5a	56.3ab
SAMSOY-2	30.7a	28.4a	54.5a	30.1a	34.7a	63.5a	30.4a	31.5a	59.0a
SAMPEA-7	27.0bc	26.3a	51.2a	29.0ab	29.6a	56.0a	28.0b	28.0a	53.6ab
IT96D-724	29.2ab	32.5a	49.4ab	26.0bcd	33.9a	54.6ab	27.6b	33.2a	52.0b
N rate (kg ha^{-1})									
30	28.3ab	26.7b	66.5a	29.2a	27.3c	75.3a	28.7a	27.0c	70.9a
60	28.7a	28.6b	44.5b	26.7b	30.3b	50.5b	27.7a	30.4b	47.5b
90	26.2b	34.4a	33.9c	25.8b	33.9a	35.4c	26.0b	34.2a	34.6c
Mean	27.7A	29.9A	48.3B	27.2A	31.2A	53.7A			

[a]Within year and treatment (previous crop, or N rate) means followed by the same letter are not significantly different at *P* 0.05 according to Fisher's LSD.

weed and pest management, optimum crop density, supplies of nutrients other than N and best adapted cultivar usually obtained in on-station experiments.

Similar values in the range of 50-80% were recorded in other well-managed field trials (Cassman et al., 1993; Peng and Cassman, 1998; Dobermann et al, 2000).

The higher recoveries under legume rotations could be due to increase in soil- N. Although Yusuf et al. (2009b) observed a mean soil N balance value of -13 kg N ha^{-1} following the rotation grain legume genotypes used in this study. Wichern et al. (2008) showed that the below-ground pool of legume N, which is often neglected in calculating soil N balance following legumes, is an important source of N for following crops. They reported a wide range (4 - 71%) of N derived from rhizodeposition (NdfR) with a median of 16% of total plant-N for various legumes. Similarly, the median of the entire below-ground plant biomass N (BGP-N) was estimated as 34% of total plant-N. When soil-N content is increasing, the amount of sequestered N contributes to a higher nitrogen use efficiency (NUE) of the cropping system, and the amount of sequestered N derived from applied N contributes to a higher RE_N (Cassman et al., 2002). The benefit in fallow rotation may lie in improved soil moisture condition, reduction of erosion and N load in surface water.

N fertilizer recovery efficiency declined as N fertilizer. Similar values in the range of 50-80% were recorded in other well-managed field trials (Cassman et al., 1993; Peng and Cassman, 1998;

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The higher recoveries under legume rotations could be due to increase in soil-N. Although Yusuf et al. (2009b) observed a mean soil N balance value of -13 kg N ha^{-1} following the rotation grain legume genotypes used in this study. Wichern et al. (2008) showed that the below-ground pool of legume N, which is often neglected in calculating soil N balance following legumes, is an important source of N for following crops. They reported a wide range (4 - 71%) of N derived from rhizodeposition (NdfR) with a median of 16% of total plant-N for various legumes. Similarly, the median of the entire below-ground plant biomass N (BGP-N) was estimated as 34% of total plant-N. When soil-N content is increasing, the amount of sequestered N contributes to a higher nitrogen use effi-

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N fertilizer recovery efficiency declined as N fertilizer rates increased (Table 3). With this behaviour of RE_N, it can be argued that the response to fertilization was very poor but analysis of grain yield and N uptake showed significant differences between all fertilizer rates (Table 2). In this respect, decreasing efficiency at higher N rate may be due to greater losses from the system as suggested by Huggins and Pan (2003). Therefore, there is need for improvement in the current fertilizer N management practice. Some interesting study has been carried out by Doberman et al., 2002 who used the field specific management approach to study the response of N, P and K as a function of timing of fertilizer application in 179 sites in 8 rice- producing domains of 6 Asian countries. Their results showed that smaller preplant doses and 2 or 3 top dressings instead of one large N-fertilizer application and one additional N top dressing led to increase in yield and reduction in N-fertilizer rate. These resulted in significant gain in RE_N and profit. There is no doubt that improvements in yield and RE_N can be achieved in the NGSN by conducting large scale 'field-specific' fertilizer trials instead of depending on a single, standard fertilizer recommendation for an entire region.

Conclusion

The present study showed that rainfall distribution affected grain yield and RE_N, which were higher in 2005 than in 2004. Rotation with grain legumes gave consistently higher grain yield and all N efficiency indices than fallow-maize and continuous maize. The overall performance of the previous legume crops in improving grain yield and N efficiency could be ranked as: SAMSOY-2 > TGx 1448-2E > SAMPEA-7 > IT 96D- 724. Maize yield showed additional response to fertilizer rates even at 90 kg N ha^{-1} suggesting that higher yields could be obtained with increasing N rates. However, all N efficiency indices except PE_N declined as N fertilizer rates increased, reflecting a poor crop use of N fertilizer. This shows that although rotation with grain legumes play a vital role in increasing maize yield, higher levels can be attained by improving N fertilizer management. Decreasing efficiency at higher N rate may be due to greater losses from the system suggesting the need for improvement in the current fertilizer N management practice. Smaller initial doses and 2 or 3 top dressings instead of one large N-fertilizer application and one additional N top dressing might lead to increase in yield and reduction in N-fertilizer rate. In addition, conducting large scale 'field-specific' fertilizer trials instead of depending on a single, standard fertilizer recommendation for the entire NGSN will be highly desirable to improve crop yield and nutrient use efficiency.

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