

# Optimizing Fertilizer Use by Smallholder Farmers and Economic Returns to Maize in Semi-arid Niger

Nouri Maman<sup>1</sup>, Gonda Abdou<sup>2</sup> and Maman Garba<sup>2</sup>

1. Institut National de la Recherche Agronomique du Niger (INRAN), Département des Culture Pluviales, Maradi BP 240, Niger

2. Institut National de la Recherche Agronomique du Niger (INRAN), Département de Gestion des Ressources Naturelles, Niamey BP 429, Niger

**Abstract:** Maize (*Zea mays* L.) is an important food crop in Niger, but low and irregular rainfall combined with sandy soils having low fertility level limit productivity. A two-year study was conducted at Institut National de Recherche Agronomique du Niger (INRAN) stations in Tarna/Maradi and Bengou/Gaya in 2014 and 2015 in order to evaluate maize agronomic and economic fertilizer use efficiency. The experimental design was a randomised complete block design (RCBD) with three replications. Results indicate higher effect of fertilizer in 2015 compared to 2014. At low N rates 20 kg N/ha and 40 kg N/ha, application of 20 kg P/ha increased maize grain yield across locations and years. The highest agronomic efficiency of N (AEN) was recorded with 60 kg N/ha in 2015 at Bengou and Tarna with 9.65 kg and 14.05 kg grain yield per kg of applied N, respectively. At Tarna, the low N rates of 20 kg N/ha and 40 kg N/ha recorded important AEN of more than 12 kg yield increases per kg of applied N. The highest rainfall use efficiency (RUE) of 6.13 kg/year/mm was obtained with application of 80 kg/ha N, 0 kg/ha P and 40 kg/ha N, 20 kg/ha P in 2015 at Tarna. Without P, the highest value cost ratio (VCR) value of 4.31 was recorded at Tarna in 2015 with 60 kg/ha N, and the lowest value of 0.08 at Bengou in 2014 with 20 kg/ha N. Based on VCR and RUE derived from this study, the optimal fertilizer recommendation for maize in the semi-arid conditions of Niger could be 40 kg/ha N, 20 kg/ha P and 0 kg/ha K.

**Key words:** Maize, agronomic efficiency, semi-arid, fertilizer recommendation, nutrient use efficiency, rain use efficiency, profitability of fertilizer use.

## 1. Introduction

Maize (*Zea mays* L.) is an important food crop in Niger, ranking fourth after pearl millet (*Pennisetum glaucum* (L.) R. Br.), sorghum (*Sorghum bicolor* (L.) Moench) and rice (*Oryza sativa* and *O. glaberrima*). Most of the consumed maize in Niger is imported from the neighboring countries of Nigeria, Benin and Burkina Faso. Maize production in Niger is low due to the low and irregular rainfall combined with very sandy soils with low fertility. The maize area of production is very small and limited to soils with more clay content in low lands and valleys. However, the area has increased from 12,398 ha in 2010 to 32,154 ha in 2015 due to efforts to increase its production [1]. At the same time, the grain yield increased from 760

kg/ha in 2010 to 1,760 kg/ha in 2015 [1]. Maize in Niger has not been the subject of intense scientific research both by Institut de Recherches Agronomiques Tropicales (IRAT) and Institut National de Recherche Agronomique du Niger (INRAN), compared with other cereals, such as pearl millet, sorghum and rice [2]. Currently, only four varieties are registered in the National Catalogue of Plant Species and Varieties: P3 Kollo, CET, EV 84-22 RS and MAKKA. The variety developed since 1970 by the IRAT [2] remains the most popularized in Niger. There is now progress in the development of new varieties and hybrids that are more productive than those commonly used. Maize has better response to nutrients applied than sorghum and pearl millet and its grain price is higher, thus application of fertilizer can be more economically profitable. In Niger, as in the West Africa (WA) Sahelian countries, soil water deficits often constrain

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**Corresponding author:** Nouri Maman, Ph.D., research fields: crop physiology and production.

maize yield, but more effective management of nutrient supply is important [3], including use of fertilizer and other good agronomic practices [4]. Most of the reported studies on maize response to fertilizer application are from Guinea Savanna and other areas of West Africa with sub-humid and humid growing seasons [5-8]. There is limited information on maize response to nutrient reported from Niger. It was reported by Pandey [9] a mean increase in maize yield of 0.65 Mg/ha with 50 kg/ha N applied. The economics of fertilizer use is a constraint, including risk of investing in inputs due to output price instability and frequent crop failures [10], and financial constraints which enhance vulnerability to risk, but also limit farmers' capacity for fertilizer use [11].

This study aimed at determining the best maize response to nutrients application and water use, which provides the high economic return to farmers and is easily accessible and adoptable.

## 2. Materials and Methods

### 2.1 Study Area

The study was conducted on two research stations: Tarna/Maradi (13°27'33" N, 07°6'14" E), and Bengou/Gaya (11°58'44" N, 03°33'29" E). The soils

were classified as Arenosols [12] at both sites. The two sites have a monomodal rainfall distribution. Maradi is located in the Sahel agroecological zone (AEZ) in South-Central-East of Niger with annual mean rainfall of 600 mm with 85% occurring from July to September. Monthly mean maximum and minimum temperatures range from 28 °C to 42 °C and 12 °C to 29 °C. Maize is produced mostly in the Goulbi valley with better soil quality, compared to the upland soils where dryland crops are produced. Bengou/Gaya is located in the Northern Sudan Savanna, a relatively small area in Southwest Niger with a mean annual rainfall of 800 mm. Rainfall distribution is similar to the Sahel AEZ, but with a longer season beginning in June. Monthly mean maximum and minimum temperatures range from 31 °C to 40 °C and 19 °C to 27 °C, respectively.

The soil test results indicate that soil of the sites is moderately acid (pH = 6.2-6.8) with 2.5-6.2 g/kg organic C, low total N, Mehlich-3 P of 72-102 mg/kg, low exchangeable bases and 417-663 g/kg of sand (Table 1). Soil sand content was less and nutrient availability was greater at Tarna/Maradi compared with Bengou. The rainfalls during the two years of the study were in the range of the long-term average for both Tarna/Maradi and Bengou sites (Table 2).

**Table 1 Chemical and physical characteristics of the soils at Tarna and Bengou, Niger.**

Soil variables	Tarna/Maradi	Bengou/Gaya
pH-H <sub>2</sub> O (1:1)	6.56	6.18
Organic C (g/kg)	6.18	2.54
Total N (g/kg)	0.48	0.22
Mehlich-3 P (mg/kg)	102	72
Available K (mg/kg)	102.18	72.15
Ca (meq/100 g)	6.97	2.39
Mg (cmol(+)/kg)	2.25	0.67
Na (cmol(+)/kg)	0.34	0.10
Bo (mg/kg)	0.24	0.18
Mn (mg/kg)	70.03	45.88
Zn (mg/kg)	8.83	8.66
Silt (g/kg)	243	121
Sand (g/kg)	417	663

**Table 2 Monthly rainfalls (mm) in 2014 and 2015 for Gaya and Tarna, Niger.**

Month	Tarna/Maradi			Bengou/Gaya		
	Average*	2014	2015	Average*	2014	2015
May	23	24	1	91	89	19
June	64	23	34	125	99	54
July	149	173	166	178	133	180
August	175	120	229	226	199	277
September	75	91	65	160	205	236
October	7	0	0	17	11	30
Total	494	534	495	797	755	797

\* Long-term average for Maradi and Gaya.

**Table 3 Fertilizer rates.**

Treatments	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	Mg (kg/ha)	B (kg/ha)
T1	0	0	0				
T2	20	0	0				
T3	40	0	0				
T4	60	0	0				
T5	80	0	0				
T6	0	20	0				
T7	20	20	0				
T8	40	20	0				
T9	60	20	0				
T10	80	20	0				
T11	60	10	0				
T12	60	30	0				
T13	60	20	10				
T14	60	20	20				
T15	60	20	30				
T16	60	20	20	15	2.5	10	0.5

## 2.2 Experimental Design and Management

The experimental design is a randomised complete block design (RCBD) with three replications. The treatment structure is an incomplete factorial with five N levels (0, 20, 40, 60 and 80 kg/ha) without P and with P levels (10, 20 and 30 kg/ha); K (0, 10, 20 and 30 kg/ha) with N levels 60 kg/ha and P 20 kg/ha; a diagnostic treatment: 15 kg/ha S, 2.5 kg/ha Zn, 10 kg/ha Mg and 0.5 kg/ha B combined with NPK rate comparable to another treatment. The treatment structures were presented in Table 3.

The sources of N, P and K were urea, triple superphosphate (TSP) and potassium chloride (KCl), respectively. Magnesium sulfate was used as the source of Mg, borax ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$ ), zinc-sulfate

( $\text{ZnSO}_4$ ) and calcium carbonate ( $\text{CaCO}_3$ ) were used as the sources of B, Zn and Ca.

The fertilizers were point applied 5-10 cm from the hills and incorporated 7-10 d after crop emergence. N fertilizer was applied with half rate at the same time with P, K and the micronutrient fertilizers application and the remaining half at the boot stage.

The variety used in the two sites was P3 Kollo with 80-85 d to maturity and yield potential of 2,500-4,000 kg/ha, developed in the 1980s by IRAT [13]. The experimental sites were ploughed and harrowed. Plots of 6 m × 6 m (36 m<sup>2</sup>) size were marked out for all the treatments with 2 m alley between blocks. The seeds were treated with Apron Star 42W (Syngenta product containing active ingredients thiamethoxam,

mefenoxam and difenoconazole with 20, 20 and 2 g/kg active ingredient (a.i.), 5 g/kg seed) to avoid damping-off and assure a good emergency with vigorous seedlings and sowed manually at a depth of 5 cm.

Spacings used were 0.8 m between rows and 0.4 m within rows, and the seedlings were thinned to 2 plants/hill after the first weeding to have a plant population of 62,500 plants/ha. Sowing dates were July 3rd and July 17th in 2014 in Tarna and Bengou. In 2015, maize was sowed on June 27th in Tarna and July 9th in Bengou. Manual hand-hoeings were conducted at the third and sixth weeks after sowing to control weeds. In 2014, maize was harvested on October 16th in Tarna and October 23rd in Bengou. In 2015, the harvesting dates were October 24th in Tarna and October 28th in Bengou.

### 2.3 Data Collection

Soil samples were gathered from 10-15 points at 0-20 cm soil depth to form composite samples for each block, then air dried, sieved through a 2 mm sieve and sent to World Agroforestry Centre (ICRAF) laboratory in Nairobi, Kenya for determination of particle size distribution, pH, organic carbon (OC), total N, Mehlich-3 P and exchangeable K, Ca, Mg and Na.

Data collected from the two central rows of 4 m long of plot included number of plants, number of panicles, weight of panicles and grain weight.

### 2.4 Data Analysis

Analysis of variance (ANOVA) was used to determine variation in yield due to different levels of N, P and K by site and year and combination across site-year. The effect of N and P fertilizer and their interactions were the primary focus of the analysis. When significant effects of N rate by P rate did not occur, asymptotic regression was fitted to the yield data in order to determine response to N. The asymptotic function is given as yield ( $y$ ) (kg/ha) by Eq.

(1):

$$y = a - bc^N \quad (1)$$

where,  $a$  is yield at the plateau (i.e., expected maximum),  $b$  is the amplitude (the gain in yield due to nutrient application),  $c$  is a curvature coefficient and  $N$  is the nutrient rate applied. The regression analyses for N rate effects included treatments with and without P.

Rain use efficiency (RUE), defined as the ratio of grain yield to seasonal total rainfall was calculated and used as proxy for water use efficiency (WUE). Therefore, RUE was used in this study as a metric for evaluating WUE.

Nutrient use efficiency (NUE) by maize was assessed focusing on the agronomic efficiency of N (AEN) at fixed P rates and agronomic efficiency of P (AEP) at fixed N levels. Therefore, it closely reflects impact of the applied N fertilizer. AEN was calculated as a ratio of the increased crop output to the amount of N applied. AEP was calculated in a similar manner.

The third analysis focused on determining returns to fertilizer use. For this purpose, the value cost ratio (VCR) was used, because it is commonly used when assessing the profitability of fertilizer use, especially in the absence of data on full production costs. Hence, VCR was calculated as a ratio of value of increased crop output to the cost of fertilizer applied.

All analyses were done using the Statistix 10 (Analytical Software, Tallahassee, FL).

## 3. Results

### 3.1 Overall Yield Response

Grain yield and response to fertilizer application were greater in 2015 than in 2014 (Figs. 1 and 2). In the more productive year of 2015, the highest grain yield of 3,203 kg/ha was obtained at Tarna (Fig. 1) with the diagnostic treatment of 60-20-20 + micronutrients, which was 24% more yield than with the same N, P and K rates. However, at Bengou during the same year, the highest yield of 2,915 kg/ha was obtained with the treatment of 60-30-0, indicating that the increase in P rate had more effective yield

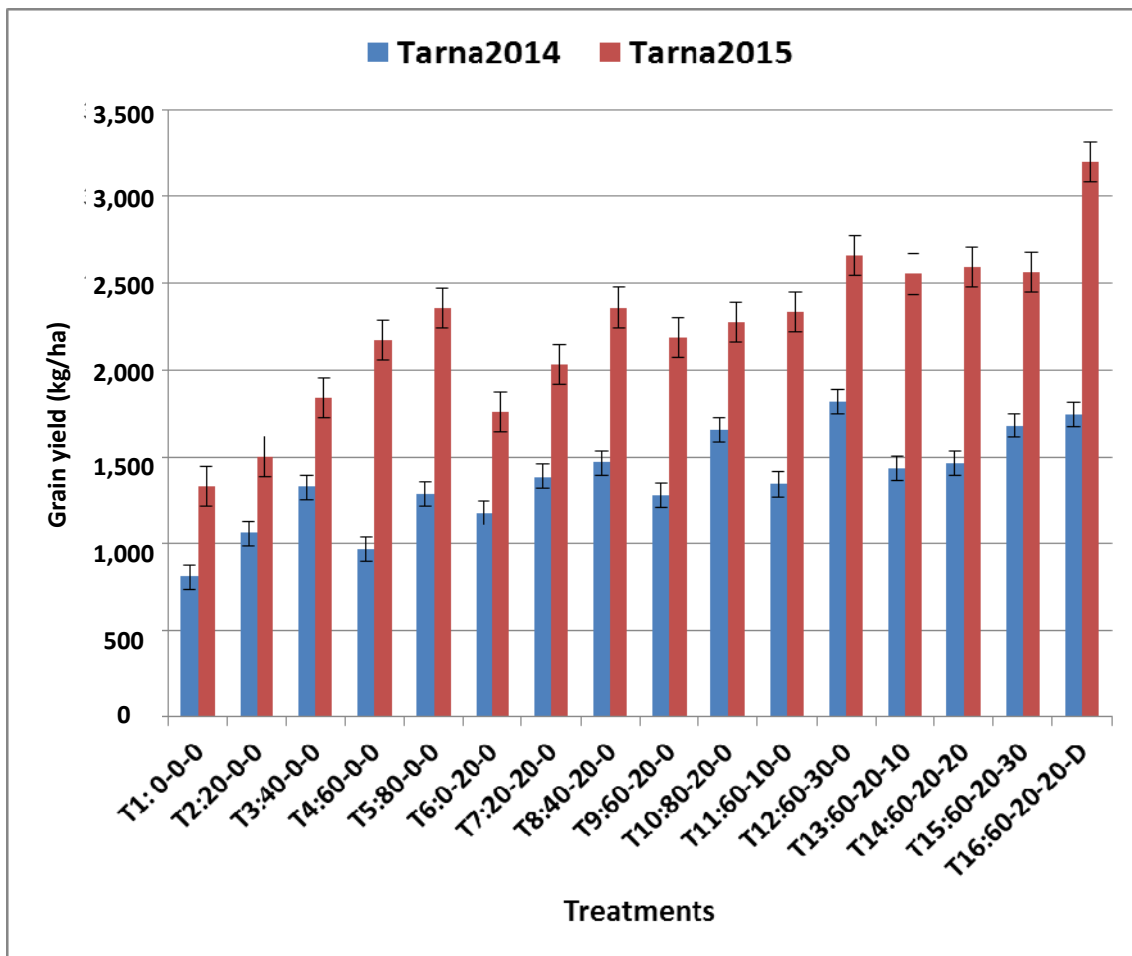


Fig. 1 Maize grain yield response to applied nutrients at INRAN research station in Tarna/Maradi, Niger. T1-T16: N, P and K rates (kg/ha).

increase of 25% than the diagnostic treatment. In the least productive year of 2014, the highest yield was obtained under the treatment 60-30-0 with 1,821 kg/ha at Tarna and with treatment of 60-20-20 at Bengou with 2,427 kg/ha.

### 3.2 Response to N

Table 4 presented the results of maize response to N fertilizer rates at the two locations in 2014 and 2015. There was a maize yield response to N rates without P fertilizer application; when in Tarna in 2014, the highest maize grain yield of 1,327 kg/ha was obtained with 40 kg/ha N. The relationship of maize grain yield to N rates was best fitted with a second degree polynomial equation (Fig. 3). This indicates that the maximum maize yield increase was not reached with

80 kg/ha N. The response of maize to N rates with fixed 20 kg/ha P was not significant. The N response at the fixed P rates, 0 kg/ha and 20 kg/ha presented in Table 5 indicated that the algorithm of the asymptotic regression model Eq. (1) did not converge in 2014 at Bengou and in 2015 at Tarna/Maradi. Fig. 4 gave another view of the maize response to increased N rates with 0 kg/ha and 20 kg/ha P. At the low N rates 20 kg/ha and 40 kg/ha, application of 20 kg/ha P led to 9% to 17% increase of maize grain yield over all locations and years. However, application of 20 kg/ha P increased maize grain compared to the application of 20 kg/ha N only, except for Bengou in 2014.

### 3.3 Response to P

Maize response to P fertilizer rates when N is fixed

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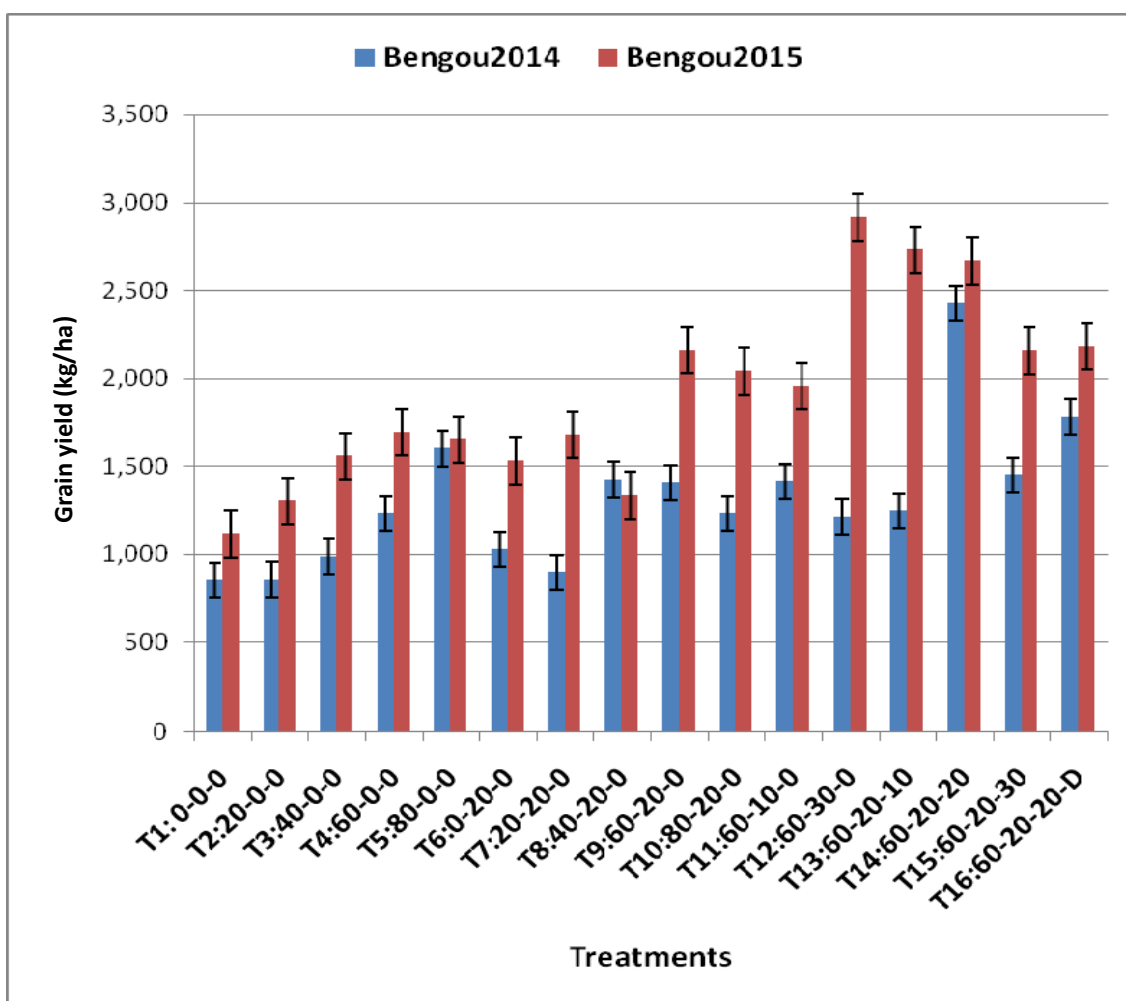


Fig. 2 Maize grain yield response to applied nutrient at INRAN research station in Bengou/Gaya, Niger. T1-T16: N, P and K rates.

Table 4 Variation in maize grain yield (kg/ha) response to applied N rates at fixed P levels.

Fixed P rate (kg/ha)	N rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
0	0	948	1,177	808	1,330
	20	1,163	1,385	1,060	1,501
	40	1,019	1,851	1,327	1,840
	60	1,192	1,788	966	2,172
	80	1,925	1,941	1,284	2,357
<i>F</i> value		6.71	5.14	1.62	8.87
<i>p</i> value		0.011	0.024	0.261	0.005
20	0	1,029	1,532	1,177	1,762
	20	895	1,680	1,385	2,033
	40	1,423	1,334	1,467	2,359
	60	1,405	2,161	1,276	2,189
	80	1,230	2,041	1,655	2,281
<i>F</i> value		2.71	2.19	0.85	1.14
<i>p</i> value		0.107	0.161	0.529	0.404

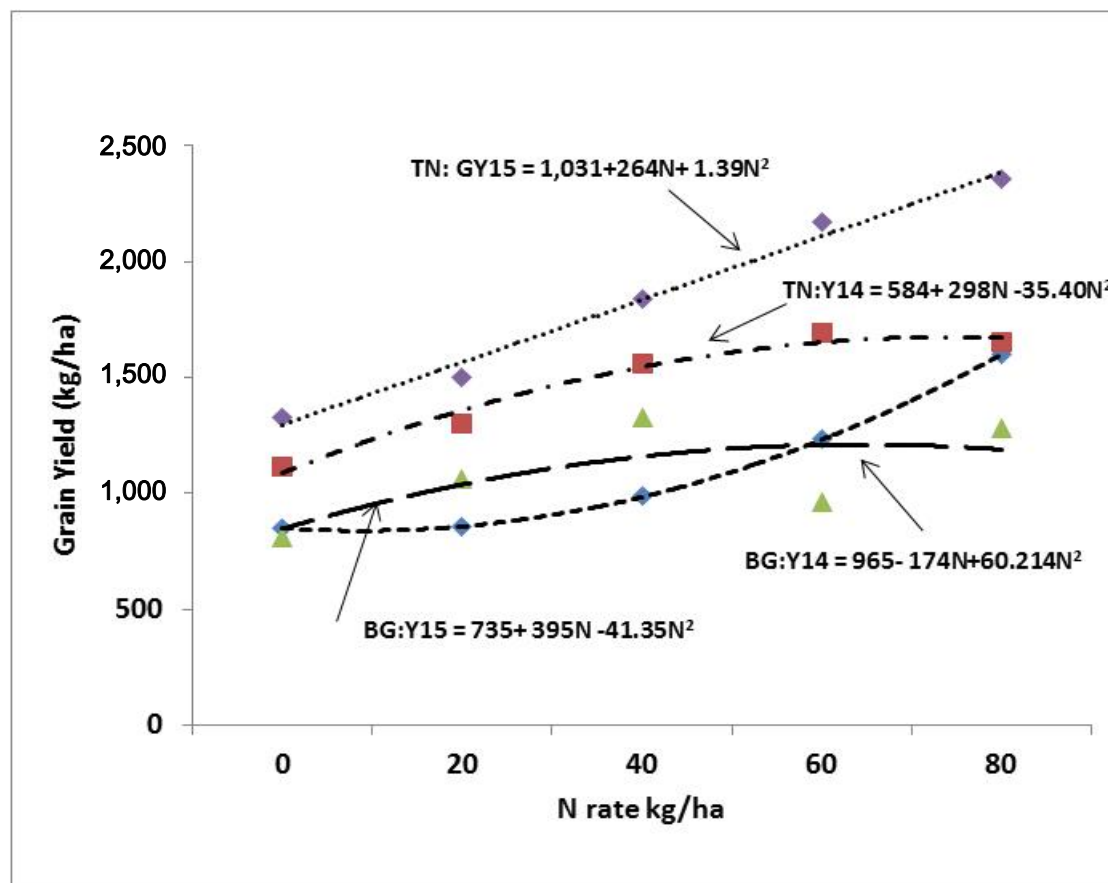


Fig. 3 Maize yield response function of N rate in 2014 and 2015.

BG:Y14, BG:Y15 = grain yield in Bengou in 2014 and 2015; TN:Y14, TN:GY15 = grain yield in Tarna in 2014 and 2015.

Table 5 Coefficients of the asymptotic N response function at fixed P rate (e.g., 0 kg/ha and 20 kg/ha).

P rate (kg/ha)	Coefficients	Bengou		Tarna	
		2014*	2015	2014	2015*
0	a	-	2.11	1.19	-
	b	-	0.95	0.38	-
	c	-	0.98	0.93	-

a, b and c are the coefficients of the asymptotic regression model.

\* At Bengou in 2014 and at Tarna in 2015, the algorithm did not converge.

constant to 60 kg/ha presented in Table 6 indicated significant yield increase at Bengou in 2015 and Tarna in 2014 ( $p < 0.05$ ), when the highest yields were obtained with 60 kg/ha N + 30 kg/ha P with respectively 2,915 kg/ha and 2,664 kg/ha.

### 3.4 Nutrient Use Efficiency

Maize AEN presented in Table 7 indicated no significant difference with 0 kg/ha P, but the highest efficiency was recorded with 40 kg/ha N in 2015 at Bengou and 60 kg/ha N in 2015 at Tarna with

respectively 11.08 kg and 14.05 kg grain yield per kg of applied N. At Tarna, the low N rates of 20 kg N/ha and 40 kg N/ha recorded important AEN of more than 12 kg yield increases per kg of applied N. AEP presented in Table 8 is higher with 20 kg/ha N in all sites and years with an average of 40 kg vs. 15 kg at Bengou and 33 kg vs. 20 kg at Tarna.

### 3.5 Rain Use Efficiency

The highest RUE is 6.13 kg/year/mm with 80 kg/ha N, 0 kg/ha P and 40 kg/ha N, 20 kg/ha P in 2015 at

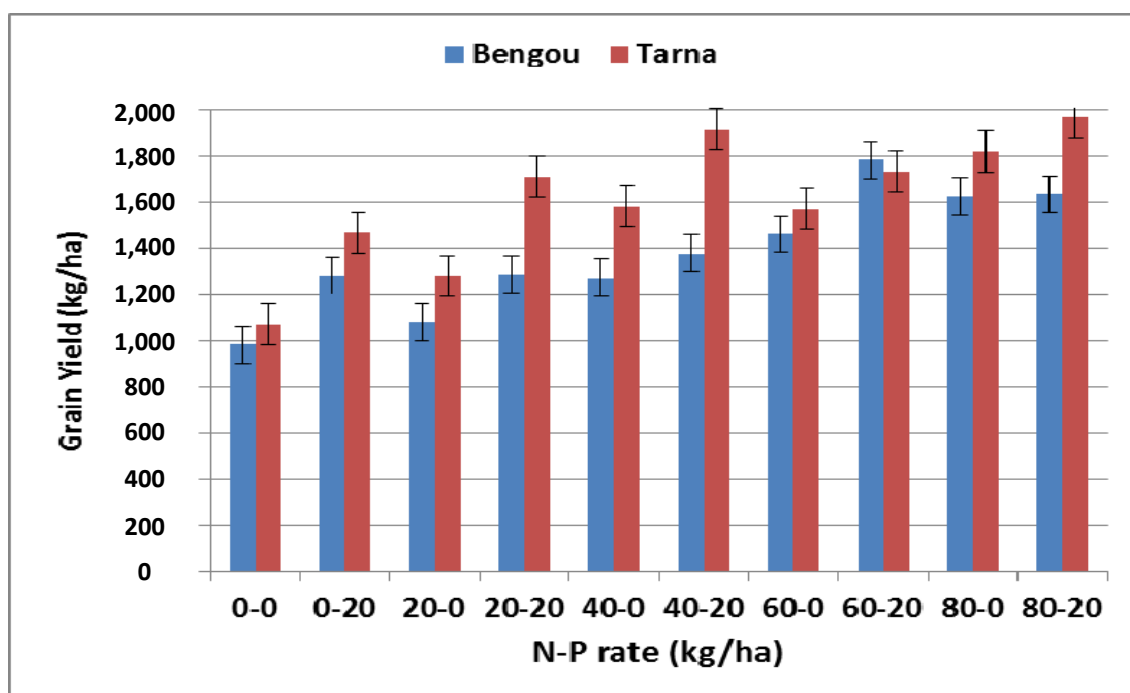


Fig. 4 Maize responses to N and P fertilizer rates in Niger.

Table 6 Variation in maize yield (kg/ha) response with P application rates at fixed rates of N (60 kg/ha).

N rate (kg/ha)	P rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
60	0	1,233	1,694	966	2,172
	10	1,413	1,956	1,342	2,335
	20	1,405	2,161	1,276	2,189
	30	1,212	2,915	1,821	2,664
<i>F</i> value		0.180	3.390	7.590	1.160
<i>p</i> value		0.689	0.094	0.018	0.399

Table 7 Variation in AEN (kg increase/kg of applied N) with N application rates at affixed P levels of 0 kg/ha and 15 kg/ha.

Fixed P rate (kg/ha)	N rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
0	0				
	20	0.25	9.40	12.58	8.59
	40	3.38	11.08	12.96	12.767
	60	6.35	9.65	2.63	14.047
	80	9.37	6.72	5.94	12.847
<i>F</i> value		0.69	0.66	1.28	0.66
<i>p</i> value		0.589	0.608	0.364	0.604
20	0				
	20	2.16	28.27	28.85	35.19
	40	14.30	5.50	16.47	25.73
	60	9.23	17.44	7.79	14.33
	80	4.73	11.58	10.58	11.89
<i>F</i> value		3.9	2.36	1.49	8.44
<i>p</i> value		0.105	0.185	0.309	0.034



**Table 8** Variation in AEP (kg increase per kg/ha P) at affixed rate of 0 kg/ha N.

N rate (kg/ha)	P rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
0	0	20.86	8.90	21.64	18.43
	20	52.31	27.70	42.99	23.38
<i>F</i> value		3.11	2.85	1.68	0.21
<i>p</i> value		0.219	0.233	0.324	0.693

**Table 9** Variation in RUE (kg/year/mm) due to applied N rates at fixed P levels (e.g., 0 kg/ha and 15 kg/ha).

Fixed P rate (kg/ha)	N rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
0	0	1.66	1.70	2.15	3.46
	20	1.67	1.99	2.82	3.90
	40	1.92	2.38	3.53	4.79
	60	2.40	2.59	2.57	5.65
	80	3.11	2.52	3.42	6.13
<i>F</i> value		4.13	5.14	1.62	8.87
<i>p</i> value		0.042	0.024	0.261	0.005
20	0	2.00	2.34	3.13	4.58
	20	1.74	2.56	3.69	5.29
	40	2.77	2.04	3.91	6.13
	60	2.73	3.30	3.40	5.69
	80	2.39	3.12	4.41	5.93
<i>F</i> value		2.71	2.19	0.85	1.14
<i>p</i> value		0.108	0.161	0.529	0.405

**Table 10** Variation in returns to fertilizer use (VCR) due to applied N rates at fixed P levels of 0 kg/ha and 20 kg/ha.

Fixed P rate (kg/ha)	N rates (kg/ha)	Bengou		Tarna	
		2014	2015	2014	2015
0	0	-	-	-	-
	20	0.08	2.88	3.86	2.63
	40	1.04	3.40	3.98	3.92
	60	1.95	2.96	0.81	4.31
	80	2.87	2.06	1.82	3.94
<i>F</i> value		0.69	0.66	1.28	0.66
<i>p</i> value		0.589	0.608	0.364	0.604
20	0	0.88	2.06	1.82	2.14
	20	0.16	2.11	2.16	2.63
	40	1.72	0.66	1.98	3.09
	60	1.39	2.63	1.18	2.16
	80	0.82	2.00	1.83	2.05
<i>F</i> value		0.95	0.52	0.27	0.40
<i>p</i> value		0.482	0.726	0.888	0.801

-: fertilizer is not applied so the VCR cannot be calculated.

Tarna (Table 9). Considering the semi-arid situation of Niger, these results indicate that maize efficiently used rainfall in these situations.

### *3.6 Returns to Investment in Fertilizer*

VCR or returns to fertilizer use due to applied N rates at fixed P levels of 0 kg/ha and 20 kg/ha (Table 10) varied significantly among N rates, but without significant difference. The highest VCRs (2-4) were recorded during the higher production year of 2015 at all the two locations. Under 0 kg/ha P condition, the highest VCR value of 4.31 was recorded at Tarna in 2015 with 60 kg/ha N, and the lowest value of 0.08 at Bengou in 2014 with 20 kg/ha N. The VCR values were lower for all N rates with 20 kg/ha P compared to 0 kg/ha P, with a high value of 3.09 in 2015 at Tarna. The results indicated that it was not economically beneficial to add P, even though the soils at the experimental sites are poor in P.

## **4. Discussion**

Regardless of the treatments, maize grain yields were higher during the 2015 cropping season, compared to 2014 at both sites. This could be explained by the rainfall received in 2015 (Table 2), which contributed to soil moisture conservation, and by the way, increased the nutrient assimilability by crops. Low and poorly distributed rainfall can reduce the availability of nutrients to maize plants [14]. Rainfall supply is one of the most critical factors limiting crop growth and yield. Thus, according to Mason et al. [15], limited and erratic rainfall, short and variable growing season are all obstacles to crops production. In rain-fed agriculture, where productivity is limited by rainfall, RUE is also shown to account for rainfall variability and to some extent local soil characteristics [16]. RUE has also been proposed as a robust indicator of productivity and land degradation in rain-limited areas [17].

In all sites, maize grain yield at a fixed P rate increased as the N rate increased during 2014 and

2015 cropping season (Table 3) till an optimal (40-60 kg/ha N), then declined. According to Sebillotte [18], there is a peak of yield response, after which increasing the amount of amendment did not lead to yield increase. The higher effect of fertilizer observed in 2015 compared to 2014 (Figs. 1 and 2) in both locations could be explained by the regular rainfall and the fact that maize was planted earlier, which allowed the crop to grow well without presence of cropping season water stress. These results are in line with the finding of Mason et al. [15], who stated that rainfall supply is one of the most critical factors limiting crop growth and yield. The higher yield of 3,203 kg/ha obtained in 2015 at Tarna (Fig. 1) under treatment T16 (60-20-20 + micronutrients), which could be due to the addition of the micronutrient at this location. This result is confirmed by the Liebig's law (1974), which stated that the most limited factor must be corrected before seeing the effectiveness of others nutrients applied.

The maize yield response to N was best fitted with a second degree polynomial equation, which indicated the non-necessity of applying till 80 kg/ha N to obtain the maximum yield. In fact, AEN is an integrated index of fertilizer N recovery efficiency and physiological N use efficiency [19]. In most cases (Table 7), AEN at P fixed rate or N fixed rate increase with increasing application of the nutrient. These results are in line with the findings of Eftimiadou et al. [20], who found that agronomic efficiency (AE) was greater in plots treated with mineral fertilizer. But these results are contrary to the findings of Vanlauwe et al. [21], who reported that AE is low for excessive inorganic and organic fertilizer application. The AE found during this study was higher than under famer management, since they are using small amount of mineral fertilizer to lower their incomes. In fact, under farmers' practices in Africa, nutrient assimilation or recoveries by crops is only 10% to 15% of the P and 10% to 20% of the N and K applied through fertilizer [22].

The profit derived from any technology is a key entry point for its adoption by farmers, particularly the short-term cost-benefit one as reported by De Jager et al. [23]. To evaluate the profit derived from fertilizer application, VCR which measures the average gain in the value of crop output per kg of fertilizer applied was used. Technically,  $VCR = 1$  means that the value of the yield increased over the control equals the cost of the fertilizer, and hence the farmer's labour input is not rewarded. If there were no transaction costs in the acquisition of fertilizer, the incentive would be to apply fertilizer to the point where the VCR is 1. However, there is substantial uncertainty about the outcome of applying fertilizer, and transaction costs are inevitable.  $VCR \geq 2$  represents 100% return on the money invested in fertilizer and is sufficient to warrant investment in fertilizer [24]. At fixed P rate of 20 kg/ha and N rate varying from 60 kg/ha to 80 kg/ha, VCR was greater or equal to 2 in 2015 at Bengou and Tarna (Table 10), which meant a gain of 100% was obtained. These results are in line with the findings of Gonda [25], who obtained millet AE greater than 2 under application of N, P and K fertilizer at the rate of 100-200 kg/ha during 2013 cropping season. Indeed, a farming enterprise satisfies conditions for economic sustainability when the VCR is greater than 1 [26]. Moreover, technically, VCR greater than 2 would imply profitability of fertilizer as long as other inputs were not altered as the use of fertilizer [27].

## 5. Conclusions

Under low soil fertility conditions, application of amendment is necessary in order to improve crop production. Maize production could be improved and promoted through the use of mineral fertilizer, since it is economically viable. The results of this study concluded that under inherently poor sandy soil and within Sahelian conditions, farmers can increase maize production and improve their incomes through the application of mineral fertilizer. Based on VCR and RUE derived from this study, the optimal

fertilizer recommendations for the Sahel conditions of Niger could be 40 kg/ha N, 20 kg/ha P and 0 kg/ha K.

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