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Cowpea response to nutrient application in Burkina Faso and Niger

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Cowpea (*Vigna unguiculata* (L.) Walp) is important in semi-arid West Africa. Yields are low due to inadequate water and nutrient availability and other constraints. Grain and fodder yield responses to nutrient application were determined from 21 site-years of research conducted in the Sahel and Sudan Savanna. The incomplete factorial treatment arrangement varied by country but included: Four levels each of P and K in 7.5 and 10.0 kg ha^{-1} increments, respectively; Mg-S-Zn-B package (Mg-S-Zn-B); and comparable with and without manure treatments. Yield increases due to P application always occurred with curvilinear to plateau or linear responses. The overall mean grain yield increase was 0.35 Mg ha^{-1} and 47% due to application of 22.5 kg ha^{-1} P. Application of K resulted in a linear negative effect in 2014 and positive effect in 2015 for on-station trials in Niger, but had no effect in Burkina Faso and for on-farm trials in Niger. Yield was not affected by Mg-S-Zn-B in Burkina Faso but was increased by a mean of 0.085 Mg ha^{-1} in Niger. Manure application resulted in a mean yield increase of 0.1 Mg ha^{-1} in Niger but only with fertilizer P applied, and had no effect in Burkina Faso. Cowpea grain and fodder yields were responsive to fertilizer P up to 22.5 kg ha^{-1} but little affected by other applied nutrients.

Key words: Fertilizer, fodder, grain, manure, micronutrient, phosphorus, secondary nutrient, Sahel, Sudan Savanna.

INTRODUCTION

Cowpea (*Vigna unguiculata*) is an important food and cash pulse crop of semi-arid areas of Africa including in the Sahel and Sudan Savanna of West Africa because of its tolerance to soil water deficits and low nutrient availability. National mean yields vary with 2013 estimates of 0.28 Mg ha^{-1} for Niger and 0.78 Mg ha^{-1} for Nigeria (FAO, 2017). Cowpea production is often on soil of low clay and organic C contents, with low nutrient availability.

Cowpea is often responsive to applied manure and fertilizer. Adeoye et al. (2011) reported increased yields with cattle and poultry manure application. Cowpea is efficient in fixation of atmospheric N but Dugje et al.

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Table 1. Site information and soil test properties for the 0 to 0.2 m depth at the research sites in Burkina Faso and Niger.

Property	------------------ Niger ------------------				Burkina Faso	
	Bengou	Maradi	Magaria	Konni	Boni	Dori
Latitude	11.979	13.459	12.975	13.825	11.541	14.042
Longitude	3.558	7.104	8.917	5.289	-3.436	-0.136
Elevation	170	360	400	270	325	280
Soil type	Luvisol	--------- Arenosol --------			Luvisol	Arenosol
pH-H_2O	6.6	5.6	5.6	6.9	5.2	6.2

(2009) found that cowpea was often responsive to 15 kg N ha^{-1} applied at planting. Agboola (1978) reported mean cowpea grain yield increases of 0 and 0.24 Mg ha^{-1} due to 10 kg ha^{-1} N without and with P uniformly applied, respectively. However, Abayomi et al. (2008) reported that application of 40 kg N ha^{-1} depressed flowering and reduced grain yield, but increased vegetative growth. Yield was increased by a mean of 0.19 Mg ha^{-1} due to 10 kg ha^{-1} P applied (Magani and Kuchinda, 2009; Ndor et al., 2012). Abayomi et al. (2008) evaluated the effects of NPK fertilizer application and recommended the application of 150 ha^{-1} NPK fertilizer to supply 30-15-15 kg N-P-K ha^{-1} for cowpea. In consideration of available information, the International Institute of Tropical Agriculture recommended 30, 14 and 12.5 kg ha^{-1} N, P and K, respectively, for cowpea production (Dugje et al., 2009). The profit potential for fertilizer application to the pearl millet-cowpea intercrop was greater than with application to either of the sole crops (Maman et al., 2017a).

Crop-nutrient response information is important fertilizer use decisions aimed at high farmer profitability but such information is scarce for cowpea in West Africa. Field studies included 21 trials conducted in Burkina Faso and Niger to determine cowpea yield responses to fertilizer N, P, K, Mg-S-Zn-B, and manure. The hypotheses were that cowpea would be most responsive to applied P with occasional responses to other nutrients and that nutrient response would be enhanced with manure application.

MATERIALS AND METHODS

Experimental sites

Cowpea trials were conducted in the Sahel during the 2014 and 2015 on-station at Tarna-Maradi, Magaria, and Birnin Konni in Niger, and at Dori, Burkina Faso, and on-farm in Niger near Maradi and Magaria in 2014 and 2015, Birnin Konni in 2015 (Table 1). The trials at Boni Burkina Faso were conducted on-farm. The soil was Arenosol for the Sahel sites (Jones et al., 2013). Trials were conducted in the Sudan Savanna with Luvisol soil at Boni, Burkina Faso, and Bengou, Niger in 2014 and 2015. The rainfall pattern was mono-modal with >700 mm for Bengou and Boni and <600 mm for the Sahel locations (Figure 1).

Composite soil samples of 0 to 0.2 m depth were collected by block before land preparation and treatment application. The samples were air-dried, sieved to a 2-mm diameter and sent to the World Agroforestry Center Soil-Plant Spectral Diagnostic Laboratory in Nairobi, Kenya. The analyses were for particle size distribution, pH, organic C and N, exchangeable bases, S, Zn, Cu, Fe, Mn, and B (https://www.worldagroforestry.org/sd/landhealth/soil-plant-spectral-diagnostics-laboratory/sops).

Soil properties ranged from 5.2 to 6.6 pH, 1.1 to 7.6 g kg^{-1} soil organic C, 11 to 40 mg kg^{-1} Mehlich-3 P, and 41 to 94 mg kg^{-1} Mehlich-3 K (Table 1).

Experimental design and treatments

The experimental design was a randomised complete block design with three replications. Plot size was 4.8 m × 6.0 m with access alleys separating blocks. There were 16 treatments in Niger and 11 treatments in Burkina Faso (Table 2). The treatment structure was an incomplete factorial. There were four P levels with increments of 7.5 kg ha^{-1} with 0 and 20 kg ha^{-1} K uniformly applied and four K levels with 10 kg ha^{-1} increments with 15 kg ha^{-1} P uniformly applied. The Mg-S-Zn-B was applied with 15 kg ha^{-1} P and 20 kg ha^{-1} K. In Niger, treatments T_1 to T_{12} had 2.5 Mg ha^{-1} manure broadcast applied and four additional treatments (T_{13} to T_{16}) had no manure application. Treatments T_1 to T_{11} and T_{13} to T_{16} had 10 kg ha^{-1} N uniformly applied. Treatment T_{12} had no N applied. The five on-farm trials had the same design and treatment structure as for the on-station trials in Niger, but the on-farm trials had one complete block per field across five or six fields of different farmers. In Burkina Faso, adjacent experiments were conducted with and without 5 Mg ha^{-1} of manure broadcast applied.

The nutrient sources were triple super phosphate, potassium chloride, and urea. The Mg-S-Zn-B treatment had rates of 10-15-2.5-0.5 kg ha^{-1} with nutrients supplied from $MgSO_4$ as kieserite with 15% Mg and 22% S, zinc sulfate monohydrate with 34% Zn and 18% S, and granular borax with 14.5% B. Nutrient rates were specified in elemental form. The fertilizers were point applied and incorporated 0.05 to 0.1 m from the plants at 7 to 10 days after seedling emergence.

In Niger, the mean manure nutrient concentrations for N, P, K, Mg, S, Zn and B, respectively, were 10.9, 1.1, 7.3, 2.3, 0.8, 0.02 and 0.05 kg Mg–1. The mean manure pH was 8.5 and the C:N ratio was 18.6. In Burkina Faso, the mean manure N, P, and K contents, respectively, were 12, 4, and 21 kg Mg–1, and the C:N ratio was 17. The manure used in Niger was from penned goats and sheep. The manure used in Burkina Faso was a compost of cattle excrement mixed with unconsumed crop stover.

Management practices

The experimental sites were ploughed and harrowed. The variety planted was *cv* IT99K573-1-1 which has a semi-erected growth

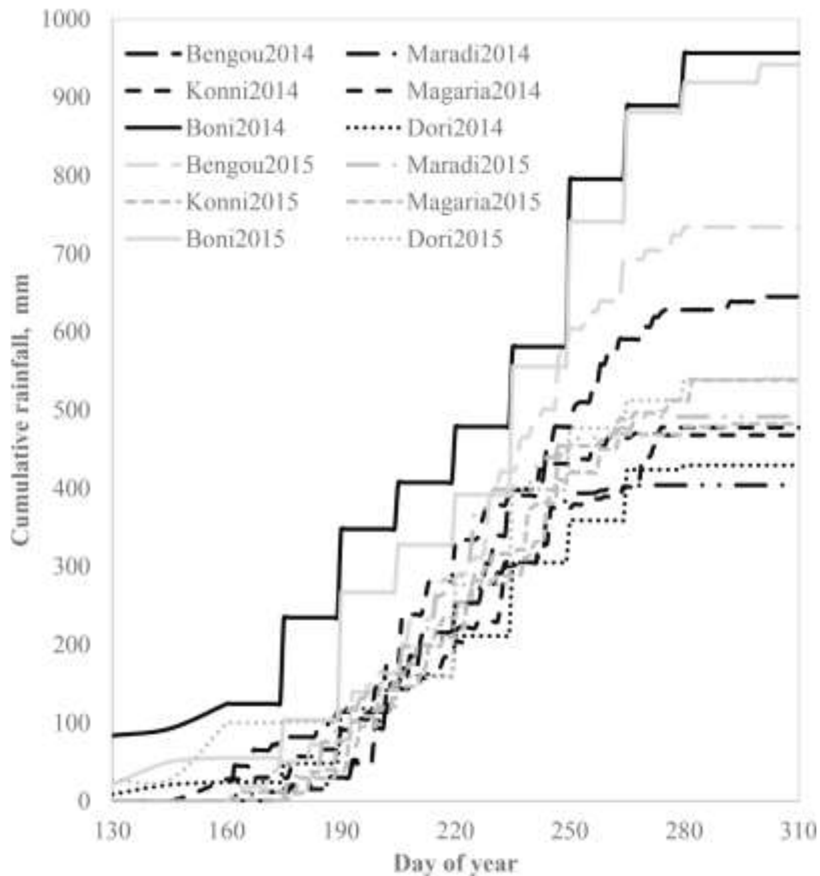

Figure 1. Cumulative rainfall for four research sites in Niger (a) and Burkina Faso (b) in 2014 and 2015.

Table 2. Nutrient rate (kg ha^{-1}) treatments (T) for cowpea response trials conducted in Niger and Burkina Faso.

T	N-P-K, Niger	T	N-P-K, Burkina Faso
1	10-0-0†	1	0-0-0
2	10-7.5-0	2	0-7.5-0
3	10-15-0	3	0-15-0
4	10-22.5-0	4	0-22.5-0
5	10-0-20	5	0-0-20
6	10-7.5-20	6	0-7.5-20
7	10-15-20	7	0-15-20
8	10-22.5-20	8	0-22.5-20
9	10-15-10	9	0-15-10
10	10-15-30	10	0-15-30
11	10-15-20-D	11	0-15-20-D
12	0-15-20		
13	10-0-0‡		
14	10-7.5-0		
15	10-15-0		
16	10-15-20		

†The nutrient rate (kg ha^{-1}) treatments refer to: N-P-K, and D, the diagnostic treatment. The diagnostic treatment contained 15 S, 10 Mg, 2.5 Zn and 0.5 B kg ha^{-1} combined with N, P, and K rates comparable to treatment 7. ‡ Treatments 1-12 in Niger had 2.5 Mg ha^{-1} manure applied and treatments 13-16 had no manure applied. Side-by-side trials in Burkina Faso had 0 or 5 Mg ha^{-1} manure applied in 2014 and were repeated on the same plots in 2015 with no more manure application.

habit with 70 to 80 days to maturity, a grain yield potential of 1.5 Mg ha^{-1} and good fodder production potential (Baoua et al., 2012). The seeds were treated with fungicide Apron Star 42 W of Syngenta {thiamethoxam [3-(2-chloro-1,3-thiazol-5-ylmethyl)-5-methyl-1,3,5-oxadiazinan-4-ylidene(nitro)amine], mefenoxam{(R,S)-2-[(2,6-dimethylphenyl)-methoxyacetylamino]-propionic acid methyl ester}, and difenoconazole [1-((2-(2-chloro-4-(4-chlorophenoxy)= phenyl)-4-methyl-1,3-dioxolan-2- yl)methyl)-1H-1,2,4-triazole] with 20, 20 and 2 g kg^{-1} a.i.; 5 g kg^{-1} of seed}. Seed was manually sown at 50-mm depth with 0.8 × 0.3 m spacing. The seedlings were thinned to 2 plant $hill^{-1}$ after the first weeding. Manual hand-hoe weeding was done at 3 and 6 weeks after sowing. The trials were sprayed at flowering and pod formation for protection against a spectrum of insect pests including *Maruca testulalis* and pod sucking coreid species with cypermethrine {[cyano-(3-phenoxyphenyl) methyl] 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate} plus dimethoate (2-dimethoxyphosphinothioylsulfanyl-N-methylacetamide) at 1 L ha^{-1}.

Data collection and statistical analysis

Upper fully expanded leaves of the treatment with 15 kg ha^{-1} P and 20 kg ha^{-1} K were sampled at flowering in Niger and analyzed for N, P, K, Ca, Mg, S, Fe, Cu, Mn, Zn, B, and Mo at the laboratory of the World Agroforestry Centre in Nairobi. This treatment was sampled to prevent suppression of expression of other nutrients deficiencies by low foliar P and K concentrations. In both countries, grain and fodder yield were determined from harvest of the two central rows for 4-m length. Harvest was by uprooting the plants from the two inner rows, removing the pods and air-drying before shelling. The harvested grain was weighed and air-dried grain yield calculated. The grain plus fodder yield was also determined on a grain value equivalent basis assuming that the value of one kilogram fodder was equivalent to the value of 0.25 kg grain.

The analysis of variance (ANOVA) was combined across within countries with years, locations, and replications as random variables and treatments as fixed variables with Statistix 10 Software (Tallahasse FL). The on-farm trials in Niger were each considered a site-year and the ANOVA was combined across site-year. In Burkina Faso, manure was a factor in the overall ANOVA. If there were significant treatment effects, overall or for location x year, contrast tests were applied to evaluate effects of N, K and Mg-S-Zn-B. Contrast tests were also applied to manure effects in Niger. The effects of P and its interactions were further analyzed with the sub-set of the first eight treatments for P rates (Table 2).

The analyses were for cowpea grain yield and for grain plus fodder yield expressed as grain yield equivalent. The grain yield equivalent was calculated assuming the value of food to be 25% of grain value. Therefore, the grain yield equivalent of grain plus fodder yield was the sum of the grain yields plus ¼ the fodder yield (Mg ha^{-1}).

Crop response to increasing nutrient rates is most typically curvilinear to plateau and the fitting of response data to an asymptotic regression function was first attempted where Yield (Mg ha^{-1}) = $a–bc^r$, with *a* being yield at the plateau due to the application of that nutrient, *b* being the maximum gain in yield due to the application of that nutrient, *c* being a curvature coefficient, and *r* being the nutrient rate (Wortmann et al., 2017). When the asymptotic function failed to give a realistic convergence, linear functions were attempted.

The economically optimum rates (EOR) of nutrient application, or the rate of maximum net profit per ha, were calculated for nutrient use cost to farmgate cowpea grain value ratios (CP) ranging from 3 to 12 kg kg^{-1}. The agronomic efficiency (AE) was calculated as the gain in grain yield per kg of P or K applied (kg kg^{-1}). The profit to cost ratio (PCR), or the ratio of net return due to the nutrient application relative to the cost of that nutrient application, was calculated for different CP and nutrient rates.

RESULTS

In Niger, the mean cowpea yields were 0.49, 0.78 and 0.67 Mg ha^{-1}, respectively, in 2014 and 2015, and for the on-farm trials. Fodder yield added an average of 60% to the value of the cowpea harvest. The year × location × treatment and the P × K interactions did not affect grain and fodder yields in the on-station trials but treatment, year, location, and year × location and year × treatment interaction effects were significant (Table 3). The year × P interaction occurred due to a small but curvilinear grain and grain plus fodder yield response to P in 2014, but linear and greater responses in 2015 (Table 4; Figure 2). The P rate effect was linear for the on-farm trials. For the on-station trials, grain and grain plus fodder yield response to K was negative in 2014, but grain yield response to K was positive in 2015. There was no K effect on yields for the on-farm trials. Grain and grain plus fodder were increased with Mg-S-Zn-B by 10% and by 19% with 10 kg ha^{-1} N for the on-station trials conducted in 2015 but not in 2014. Grain yield was also increased with Mg-S-Zn-B by 25% for the on-farm trials. There was a response to manure application only in 2015, but only with fertilizer P applied. Manure did not affect yield in the on-farm trials. The response to Mg-S-Zn-B could havbeen due to any of these nutrients. The foliar sample results indicate some cases of low N, P and K even though P and K were applied to the sampled plots (Table 5). Other foliar nutrient levels were above the critical values used for interpretation except for borderline S concentrations for some samples.

In Burkina Faso, the mean cowpea yields were 1.76 Mg ha^{-1} at Boni and 0.7 Mg ha^{-1} at Dori. Grain yield was affected by the treatment × location interaction but not by other interactions (Table 3). Grain yield had a greater and curvilinear response to P at Boni, averaged over the two years and two manure rates, compared with Dori where there was a linear response (Table 4; Figure 2). Grain yield was not affected by K, Mg-S-Zn-B, and manure application.

The effects of P were often linear with an EOR of at least 22.5 kg ha^{-1} (Table 4; Figure 2). For the linear responses at 22.5 kg ha^{-1} P, the AE ranged from 10 kg kg^{-1} at Dori to 25 kg kg^{-1} for grain plus fodder for 2015 in Niger. The corresponding ranges of PCR for CP = 12 and 3, respectively, were -0.2 to 2.3 \$ $\$^{-1}$ at Dori and 1.1 to 7.3 \$ $\$^{-1}$ for 2015 grain plus fodder in Niger. At Boni which had a curvilinear to plateau response, the EOR of P ranged from 22 to >30 kg ha^{-1} for CP = 12 to 3 and 6. The response to P in Niger in 2014 was also curvilinear to plateau with EOR of P ranging from to 4 to >30 kg ha^{-1} for grain alone and from 9 to 24 kg ha^{-1} for grain plus fodder with CP = 12 and 3, respectively. For Boni, AE at

Table 3. ANOVA results for cowpea yield response to applied nutrients in Niger for grain and grain plus fodder on a grain value equivalent basis with fodder value 0.25 kg kg^{-1} of grain.

On-station trials				On-farm trials			
Source	**df**	**Grain**	**Grain+fodder**	**Source**	**df**	**Grain**	**Grain+fodder**
Year (Y)	1	***†	**				
Location (L)	3	***	***	SY	4	***	***
YxL	3	***	***				
Treatment (T)	15	***	***	T	15	***	***
LxT	45	ns	ns	SYxT	60	ns	ns
YxT	15	***	***				
YxLxT	45	ns	ns				
Error	240				270		

† ns, not significant; ** and *** indicate significant effects at P ≤ 0.01 and 0.001, respectively.

Table 4. The P and K rate (kg ha^{-1}), N, Mg-S-Zn-B†, and manure effects on cowpea yields (Mg ha^{-1}), and P and K response coefficients, in Niger and Burkina Faso.

	Niger						Burkina Faso	
P rate	**Grain yield**			**Grain+fodder yield**			**Grain yield**	
	2014	**2015**	**OFT**	**2014**	**2015**	**OFT**	**Boni**	**Dori**
0	0.39	0.56	0.51	0.87	0.84	0.71	1.53	0.60
7.5	0.48	0.63	0.63	1.02	0.94	0.87	1.69	0.65
15	0.51	0.78	0.67	1.03	1.15	0.94	1.87	0.74
22.5	0.59	0.99	0.83	1.15	1.40	1.11	1.95	0.82
P effect	***	***	***	***	***	***	*	**
P×K effect	ns	ns	ns	ns	ns	ns	ns	ns
P response coefficients	**A‡**	**L**	**L**	**A**	**L**	**L**	**A**	**L**
a (Mg ha^{-1})	0.68	0.524	0.510	1.16	0.799	0.717	2.25	0.590
b (Mg ha^{-1})	0.29	0.019	0.013	0.31	0.025	0.017	0.72	0.010
c	0.95			0.91			0.96	
K rate								
0	0.56	0.74	0.68	0.96	1.12	0.94		
10	0.50	0.81	0.71	0.93	1.20	1.11		
20	0.47	0.81	0.67	0.84	1.15	0.93		
30	0.45	0.89	0.70	0.83	1.29	0.94		
K effect	*	*	ns	*	ns	ns		
K response coefficients								
A	0.549	0.745		0.962				
B	-0.004	0.005		-0.005				
Orthogonal contrasts								
Mg-S-Zn-B†	ns	0.077*	0.170*	ns	0.019*	ns	ns	ns
N	ns	0.145*	ns	ns	0.026**	ns		
Manure with 0P	ns	ns	ns	ns	ns	ns	ns	ns
Manure with P	ns	ns	ns	ns	0.298*	ns	ns	ns

ns: not significant; * and ** indicate significant effects at P ≤ 0.05 and 0.01, respectively. †Mg-S-Zn-B, a diagnostic treatment combined with N, P, and K at rates comparable with another treatment. ‡A, asymptotic function of $Y = a - bc^r$; L, linear function of $Y = a + br$, where r is the rate of nutrient application (kg ha^{-1}).

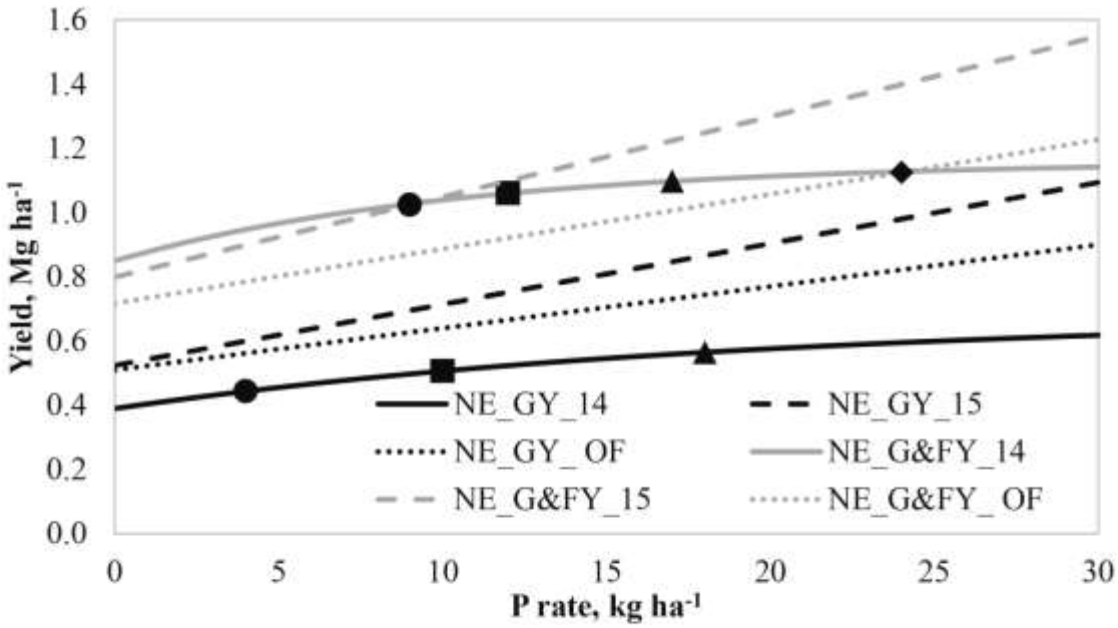

Figure 2. Response of cowpea grain yield (GY) and grain plus fodder yield (G&FY) to applied P in Niger in 2014 (_14) and 2015 (_15) with trials conducted on-station. Other trials were conducted on-farm (_OF). The economically optimal rates (EOR) of P for four fertilizer P use costs where the cost of using one kilogram of P equal to the value of 3 (●), 6, (■), 9, (▲) and 12 (♦) kg of cowpea grain, respectively. Grain plus fodder yield was the sum of grain and 25% of fodder yields.

Table 5. Cowpea foliar nutrient concentrations with sampling of upper fully expanded leaves near flowering in Niger.

Variable	N	P	K	Ca	Mg	S	Zn	Cu	Fe	Mn	B	Mo
Mean	4.0	0.39	2.7	2.6	0.66	0.28	57	12.9	1628	333	39	0.96
Minimum	3.6	0.23	1.5	1.6	0.39	0.20	46	7.2	282	216	24	0.16
Maximum	4.3	0.49	3.4	3.1	0.90	0.33	73	16.2	3440	466	46	1.53
Critical value	3.4	0.25	1.6	0.7	0.22	0.20	21	4	25	12	15	0.05

Sampled plots had 10, 15, and 20 kg ha^{-1} N, P, and K, respectively, applied after crop emergence.

EOR ranged from < 17.5 to 19.9 kg kg^{-1}, while the corresponding ranges for Niger 2014 were <7.6 to 13.5 kg kg^{-1} for grain alone and 11.6 to 19.7 kg kg^{-1} for grain plus fodder. For Boni, PCR at EOR ranged from >4.0 to 0.66 \$ $\$^{-1}$, respectively, for CP = 3 to 12. The corresponding ranges of PCR at EOR for Niger 2014 were >1.5 to 0.1 \$ $\$^{-1}$ for grain alone and 2.9 to 0.6 \$ $\$^{-1}$ for grain plus fodder.

DISCUSSION

Cowpea yields were low for the Sahel trials but much higher for Boni in the Sudan Savanna. Soil organic C and nutrient availability were low for all sites with some exceptions for Mehlich-3 P (Table 1). Rainfall was relatively more at Boni and Bengou compared with the Sahel sites in both years. Boni also had a relatively great response to applied P, apparently due to less soil water deficits. The grain yield equivalent was much increased by consideration of fodder yield (Table 2).

The greatest fertilizer use opportunity for sole crop cowpea production was with P application and response occurred independent of Mehlich-3 P (Table 4). This confirms the first hypothesis. The grain yield equivalent response to P was greater for grain plus fodder compared with grain alone. The linear and near-linear responses to P were generally associated with low to modest AE, and probably low recovery efficiency. For example, if P uptake was 5 g kg^{-1} of grain, recovery efficiency would be just 7.5% when AE is 15 kg kg^{-1}. The available information was not sufficient to determine the cause of low recovery but does suggest low capacity for P uptake and the possibility of low vascular arbuscular mycorrhizal colonization of the roots. The low to modest AE for P also implied that fertilizer P use may not always be financially practical. With the more costly fertilizer P scenario considered, fertilizer P use at Dori had a negative PCR. A PCR > 1 will likely be needed to attract investment by financially constrained farmers (CIMMYT, 1988). This was always achieved with the lower cost of fertilizer P use scenarios but never achieved with the most costly scenario considered.

Cowpea yield response to 10 kg ha^{-1} N occurred only for on-station trials conducted in Niger in 2015 (Table 4) indicating less potential than previously reported (Abayomi et al., 2008; Dugje et al., 2009). Application of 10 kg ha^{-1} N, if CP < 4, may give a satisfactory PCR. The response in 2015 and with the on-farm trials in Niger to Mg-S-Zn-B is of interest and deserves more investigation. The foliar test results show that only S was occasionally of low availability (Table 5). Sulfur is abundant and of modest cost globally suggesting feasibility for fertilizer S use, but further research is needed to determine if mean cowpea response to S, can justify the cost of fertilizer S application.

The results from Niger indicate that manure applied alone has little value but that synergistic effects of both P and manure applied occur. This supports the hypothesis of enhanced nutrient response with manure application, but only for fertilizer P. This agrees with other results from the Sahel indicating synergism of manure use with fertilizer P but not with other nutrients applied for cowpea (Garba et al., 2018).

Consideration of fodder together with grain added 60% to the value of the harvest and increased AE and PCR. Reducing CP adds greatly to profitability of fertilizer use as shown above for P. Reduced CP might also be achieved through fertilizer use subsidization, more efficient fertilizer supply, or more efficient cowpea marketing for increased farmgate value. Often PCR and AE can be increased by applying at less than EOR due to curvilinear responses such as with pearl millet, sorghum and their intercrops with cowpea and groundnut (Maman et al., 2017b, c). This has led to recommendation of microdose nutrient application for some semiarid production conditions (Bagayoko et al., 2011; Tabo et al., 2011). However, the potential for increased PCR with rates of less than EOR is much less for cowpea sole crop response to P due to the linear and near linear responses found in this study. The results support the use of cost-effective P fertilizer, such as triple super phosphate, but do not support the recommended rates and use of N-P-K fertilizer blends (Dugje et al., 2009). This consideration is especially important to financially constrained farmers as any of use of their limited resources for unprofitable fertilizer use means less available for more profitable fertilizer use.

The results of this research need to be considered together with other field research based information as was done for the development of fertilizer use decision tools (Dicko et al., 2017; Maman et al., 2017c; Ouattara et al., 2017). The decision tools are commonly used on behalf of financially constrained farmers and need to optimize fertilizer use choices for profit maximization. For example, Maman et al. (2017a) found that fertilizer use for pearl millet-cowpea intercropping had much more profit potential than for pearl millet sole crop. The computer decision tools and their paper formats are available at http://agronomy.unl.edu/ofra.

Conclusion

The yield potential of cowpea in the Sahel is low but it is much higher in Sudan Savanna where soil water deficits are generally less severe. The hypothesis that cowpea is most responsive to applied P with occasional responses to other nutrients was supported by the results of this study. The second hypothesis that nutrient response would be enhanced with manure application was found to be true only for fertilizer P. Cowpea response to P has good profit potential in both the Sahel and the Sudan Savanna if the cost of fertilizer P use relative to grain value is not too great. Phosphorus use efficiency is likely to be low which may imply P residual effects for the following crop. Cowpea fodder adds to the value of the harvest and to the response to P. Current fertilizer use recommendations for sole crop cowpea in these semi-arid areas of West Africa was found to be excessive. Fertilizer use should be limited to P, and maybe low-cost N, application until additional information justifies application of other nutrients. A research priority should be to determine the effect of S application for cowpea production. Combining fertilizer P with manure application should be practiced where feasible.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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ABBREVIATIONS

AE, Agronomic efficiency of applied nutrient use; **CP**, cost of nutrient use relative to cowpea grain value or kilogram of cowpea grain required to equal the cost of one kilogram of nutrient applied; **EOR**, the economically optimal rate of nutrient application or the rate expected to maximize net return to nutrient application; **PCR**, profit cost ratio or the net returns divided by the costs of a nutrient application.

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