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Response of Sorghum to Nitrogen Fertilizer and Plant Density in the Guinea Savanna Zone

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Abstract: Field experiments were conducted in 2007 and 2008 on sandy loam soil in Guinea savanna of Ghana to evaluate sorghum (*Sorghum bicolor* (L.) Moench) response to plant density and Nitrogen (N) fertilizer. A randomized complete block design, arranged in a split-plot was used with three replications. Four N levels (0, 40, 80 and 120 kg ha^{-1}) and plant densities (53300, 88800, 66600 and 133300 plants ha^{-1}) were assigned to subplots and main plots, respectively. Plant density and N levels showed no significant interactions for any parameter. Further, plant density had minimal effect on grain yield and yield components. However, grain yield had a quadratic response to N levels. Across years, application of 40, 80 and 120 kg N ha^{-1} resulted in yield increases of 39, 43 and 45% over farmers' practice (0 kg N ha^{-1}), respectively. Marginal Rate of Return (MRR) to 40 kg N ha^{-1} over the years was 281%, but negative to 80 and 120 kg N ha^{-1}. Increasing N level beyond 40 kg ha^{-1} did not result in corresponding increase in yield, net benefit nor N use efficiency to merit the extra production cost that may be incurred. From the study, application of 40 kg N ha^{-1} appeared adequate for maximizing sorghum yields, regardless of plant density.

Key words: *Sorghum bicolor* (L.) Moench, nitrogen levels, row spacing, grain yield, economic response

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) plays an important role as a staple food grain in many developing countries. In many smallholder farms in West Africa, little or no agricultural input is added to the soil. This leads to a decline in soil nitrogen and phosphorus which frequently results in low crop yields or soil productivity. In Ghana, sorghum grain yield from farmers' fields is estimated at 0.8 t ha^{-1}. In the past, long fallow periods of 5-10 years allowed natural restoration of soil fertility. The fallow period has decreased in length or is almost nonexistent in many farming communities in the zone because of pressure on land to increase food production and other socioeconomic activities.

Nutrient inputs from chemical fertilizers are needed to replace nutrients which are exported and lost during cropping, to maintain a positive nutrient balance. However, because of scarcity and high cost, most smallholder farmers in tropical Africa rarely use inorganic fertilizers on food crops including sorghum. Subsistence farming in sub-Saharan Africa is thus characterized by low external input, low crop yield, food insecurity, nutrient mining and environmental degradation (Stoorvogel *et al*., 1993; Rhodes, 1995; Mafongoya *et al*., 2006). Strategies must therefore be developed to restore soil fertility, to reduce erosion and environmental degradation in order to increase food production and alleviate chronic hunger in the zone (Vagen *et al*., 2005). The limited amounts of fertilizer available need to be used judiciously for maximum benefit. Since, a majority of these farmers have low income, technical packages to increase and sustain agricultural production must be affordable, profitable and applicable to ensure their acceptability.

The study has shown that application of N fertilizer increased crop yields (Buah *et al*., 1998; Workayehu, 2000; Yamoah *et al*., 2002; Aflakpui *et al*., 2005; Conley *et al*., 2005). Nitrogen demand may also increase as plant density increases. The relationship between plant density and yield of cereals has been studied extensively, but conflicting reports have led to a renewed interest in the effects of high plant densities on yield of cereals (Workayehu, 2000; Ma *et al*., 2003). Study indicated that grain sorghum yield response to row spacing was variable and dependent upon environment (Conley *et al*., 2005). Higher plant densities increased sorghum grain yields in research conducted by Huda (1988), LaFarge and Hammer (2002) and Conley *et al*. (2005), although lower populations may produce the largest yields under dry conditions where moisture stress occurs (Rees, 1986;

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Ogunlela and Okoh, 1989). Other researchers found that plant density had no effect on yield of sorghum (Gomase *et al*., 1987; Staggenborg *et al*., 1999) and maize (Ma *et al*., 2003; Aflakpui *et al*., 2005; Shapiro and Wortmann, 2006). Combined use of fertilizer and optimum plant density may increase food production and safeguard the environment for future generations. The objective of this study was to evaluate the effects of nitrogen fertilizer use and plant densities on the production of sorghum on savanna soil.

MATERIALS AND METHODS

The study was conducted at the Savanna Agricultural Research Institute experimental field at Wa in the Guinea savanna zone of Ghana. The study site is located at latitude 10°04' N, longitude 02°30'W and at an altitude of 323 m above sea level. Total annual rainfall of 992 and 1276 mm were recorded in 2007 and 2008, respectively. The study site is a semi-arid region, characterized by low, erratic and poorly distributed monomodal rainfall, averaging about 1100 mm per annum. Most of the rain in the area comes as short duration high intensity storms between May and October. Mean monthly temperatures during the growing season ranged between 26 and 30°C. The soil of the site was a sandy loam (classified as typic-plinthic Paleustalf according to the US soil Taxonomy) with a pH of 5.2 (1:1 H_2O), 0.82 g kg^{-1} organic C, 0.04 g kg^{-1} total N, 53.2 g kg^{-1} exchangeable K and 11.04 g kg^{-1} available P (Bray-1 P) in the 0-to 0.30 m depth. The soils are typical upland soils used for sorghum production in the Guinea savanna zone of West Africa.

The experiment was conducted in a split-plot arrangement of treatments in a randomized complete block design with three replications. The experimental area was ploughed and harrowed with tractor-mounted disc plough in June each year before the treatments were imposed. Main plots received uniform application of 30 kg P_2O_5 ha^{-1} as Triple Super Phosphate (TSP) prior to planting. Nitrogen and P are the most yield-limiting plant nutrients in cereal production in the area. The main plot treatments were targeted four plant densities of 53300, 66600, 88800 and 133300 plants ha^{-1}. Nitrogen levels of 0, 40, 80 and 120 kg ha^{-1} from urea were applied to the subplots. Main plots were 6.0 by 27.0 m consisting of four subplots. Each 6-row subplot measured 6.0×4.5 m. The N fertilizer was applied in two equal doses to maximize N efficiency. Thus, one half of N was applied at 10 Days After Planting (DAP) and one-half at 35 DAP, when the plants started to grow rapidly and N demand was high. All fertilizers were applied in a subsurface band about 0.05 m to the side of the sorghum row. Since, farmers do not commonly use fertilizer for sorghum production in the area, the no N fertilizer treatment was the control representing the farmers' practice.

The experiment was planted on 26th and 6th July in 2007 and 2008, respectively. Planting dates were dependent on climatic conditions. Each year, an early-maturing (105-110-days) improved sorghum variety (var. Dorado) which is used in the brewing industry and widely grown by farmers was planted at a spacing of 0.75 m between rows and the respective intra-row spacing of 0.10, 0.15, 0.20 and 0.25 m. After emergence, the seedlings were hand thinned to one per stand to achieve intended plant densities of 133300, 88800, 66600 and 53300 plants ha^{-1}, respectively. The 66600 plants ha^{-1} density is the recommended plant population for sorghum grown under dry land in the area in which this research was conducted. Weeds were controlled manually using a hand held hoe. Each treatment was repeated on the same plot each year.

Sorghum grain was harvested at physiological maturity and the grain weight was corrected to 140 g kg^{-1} water content (14%). Measurements included 50% flowering dates (days), plant height (m), biomass (aboveground dry matter) yield (kg ha^{-1}), grain yield (kg ha^{-1}) and 100-kernel weight (g). Plant height was recorded for 5 randomly selected plants at maturity by measuring the height from the ground to the tip of the panicle. Grain and aboveground dry matter yields were determined by harvesting the center two rows of each subplot. Biomass yield was based on samples dried to constant weight at 60°C. Kernel weight was determined for a sample of 100 oven-dried kernels and harvest index was calculated as a ratio of grain yield to the aboveground biomass yield on an oven-dry weight basis. Leaf chlorophyll concentration of the second leaf from the top was assessed at 50% flowering on 20 plants, with a portable Chlorophyll meter (SPAD-502 Minolta, Tokyo, Japan) and was expressed in arbitrary absorbance (or SPAD) values. All chlorophyll meter readings were taken midway between the stalk and the tip of the leaf. In addition, Leaf Area Index (LAI) was measured with a portable canopy analyzer LICOR-2000 (Li-Cor, Linclon, NE, USA) at flowering.

Data collected were subjected to Analysis of Variance (ANOVA) to establish treatment and the interactions effect on grain yield and yield components. Statistical analyses were performed with the Statistical Program SAS for Windows 9.1® (SAS Institute Inc., Cary, NC, USA). Row spacing and N levels were treated as fixed effects and year and replication were treated as random effects. Main effects and all interactions were considered significant when p = 0.05. Nitrogen Use Efficiency (NUE) was calculated as yield of the N treatment minus yield of the zero kg N ha^{-1} (control treatment) divided by the quantity of fertilizer N applied in kg ha^{-1} (Cassman *et al*., 1996). The statistical significant treatments of this experiment were subjected to economic analysis using the partial budget procedure to determine the N level that would give acceptable returns at low risk to farmers (CIMMYT, 1988). Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All costs and benefits were calculated on hectare basis in United States Dollars (US \$ ha^{-1}). The following concepts used in the partial budget analysis are defined as follows:

- Mean grain yield is the average yield (kg ha^{-1}) of each treatment in each year
- The gross benefit per ha is the product of field price of sorghum and the mean yield for each treatment
- The Total Variable Costs (TVC) is the sum of field cost of fertilizer and the cost of fertilizer application
- The net benefit per ha (NB) for each treatment is the difference between the gross benefit and the total variable costs

For each pair of treatments, a percent marginal rate of return (MRR) was calculated. The % MRR between any pair of treatments denotes the return per unit of investment in fertilizer expressed as a percentage. To obtain an estimate of these returns we calculated the MMR, which is given by the following formula:

$$\text{MRR (between treatments, 1 and 2)} = \frac{\text{Change in net benefit } (NB_2\text{-}NB_1)}{\text{Change in TVC } (TVC_2\text{-}TVC_1)} \times 100$$

Thus, a MRR of 100% implies a return of one US dollar on very dollar of expenditure in the given variable input.

RESULTS

The interaction of year with both N and row spacing was not significant across years (Table 1). In addition, year × row spacing and year × N level as well as row spacing × N level interactions were not statistically significant for grain yield and yield components, therefore data were pooled across the two years.

Crop development: Averaged over years and N levels, only biomass production and chlorophyll meter readings were significantly affected by plant density (Table 1). The lowest chlorophyll concentration (41.9 SPAD values) was obtained at the highest plant density (133300 plants ha^{-1}) and the highest SPAD reading at lower plant densities (Table 2). Sorghum had 30% more biomass production at the highest plant density (133300 plants ha^{-1}) when compared to the recommended plant density of 66600 plants ha^{-1}. Although, not statistically significant, sorghum planted at the highest plant density tended to grow taller, produce higher leaf area index and also flower earlier (Table 2).

The application of N fertilizer significantly affected days to flowering, plant height, LAI and biomass yield when averaged across years and row spacing (Table 1). On average, fertilized plants flowered five days earlier than those that were not fertilized (Table 2). The 80 kg N ha^{-1} treatment gave the highest plant height (1.26 m) and the lowest plant height was obtained from no fertilizer treatment (1.20 m). Over the years, increasing N levels significantly increased chlorophyll meter readings (SPAD values) and 120 kg N ha^{-1} had the highest value (43.3). The lowest SPAD value was obtained at zero N treatment (Table 2). At flowering, LAI values increased linearly with increasing N levels (Table 2) with the 120 kg N ha^{-1} treatment resulting in substantial increase in LAI value. Significant differences between N levels were found for biomass yield across years (Table 1, 2). There was a positive linear relationship between N level and biomass yield across years. When compared with no N fertilizer treatment, the 40, 80 and 120 kg N ha^{-1} levels resulted in 5, 16 and 23% increase in biomass yield at flowering.

Grain yield and yield components: Across both 2007 and 2008 years, plant density and N levels showed no significant interaction for 100 kernel weight, kernels per

Table 1: Analysis of variance of the effect of row spacing (RS) and N fertilizer level (N) on sorghum across 2 years (YR) in the Guinea savanna zone, 2007 and 2008

		Harvest population	Days to 50% flowering	Plant height (m)	Leaf area index	SPAD reading	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Kernels (m^{-2})	N use efficiency (kg grain kg^{-1})
SOV	df	Prob>F-value								
YR	1	0.003	0.049	0.005	0.321	0.009	0.012	0.997	0.543	0.440
RS	3	0.036	0.306	0.253	0.636	0.048	0.002	0.829	0.939	0.531
YR*RS	3	0.007	0.300	0.374	0.392	0.485	0.965	0.760	0.395	0.188
N	3	0.151	0.001	0.003	0.002	0.001	0.010	0.001	0.001	0.001
YR×N	3	0.233	0.053	0.784	0.421	0.116	0.167	0.651	0.576	0.486
RS×N	9	0.254	0.716	0.260	0.966	0.479	0.955	0.072	0.232	0.056
YR×RS×N	9	0.146	0.422	0.123	0.635	0.673	0.162	0.558	0.260	0.105

Table 2: Days to 50% flowering, plant height, SPAD reading, leaf area index and biomass yield of sorghum as affected by row spacing and N fertilizer level in 2007 and 2008

Treatments	Days to 50% flowering (day)	Plant height (m)	SPAD value	Leaf area index	Biomass yield at flowering (kg ha^{-1})
Row spacing					
0.75×0.10 m	72a†	1.15a	41.9b	1.54a	6265a
0.75×0.15 m	74a	1.12a	42.1b	1.37a	4883b
0.75×0.20 m	74a	1.10a	45.8b	1.45a	4809b
0.75×0.25 m	75a	1.08a	45.9a	1.28a	4359b
N level (kg ha^{-1})					
0	75‡	1.20	40.3	1.20	4573
40	70	1.25	41.1	1.38	4817
80	70	1.26	42.2	1.50	5298
120	70	1.24	43.3	1.61	5627
N linear	**	**	**	**	**
N quadratic	**	*	ns	ns	ns
CV (%)	3	5	12	17	22
Grand mean	74	1.11	44.0	1.42	5079

†For each parameter, means inn the same column followed by same letter(s) are not significantly different at p = 0.05 probability level. ‡*, ** and ns: Significant at 5 and 1% probability levels and not significant, respectively

Table 3: Nitrogen Use Efficiency (NUE), grain yield and yield components of sorghum as affected by row spacing and N fertilizer level in 2007 and 2008

Treatments	100- kernel weight (g)	Kernel (m^{-2})	Grain yield (kg ha^{-1})	NUE (kg grain kg^{-1} N)
Row spacing				
0.75×0.10 m	2.22a†	8143a	2058a	11.4a
0.75×0.15 m	1.80a	8665a	2029a	10.1a
0.75×0.20 m	1.99a	8201a	1954a	12.2a
0.75×0.25 m	1.95a	7985a	1910a	7.2a
N level (kg ha^{-1})				
0	1.98‡	5897	1536	
40	1.95	9146	2137	15.9
80	1.90	9333	2198	8.8
120	2.15	8619	2223	5.9
N linear	ns	**	**	**
N quadratic	ns	**	**	ns
CV (%)	17	28	21	32
Grand mean	1.99	8249	1988	10.2

†For each parameter, means inn the same column followed by same letter(s) are not significantly different at p = 0.05 probability level. ‡*, ** and ns: Significant at 5 and 1% probability levels and not significant, respectively

Table 4: Economic analysis of nitrogen fertilizer application to sorghum in 2007 and 2008

	Nitrogen level (kg ha^{-1})			
Variables	0	40	80	120
Average yield (kg ha^{-1})	1536	2137	2198	2223
Price of sorghum grain (US$ kg^{-1})	0.33	0.33	0.33	0.33
Gross benefits (US$ ha^{-1})	512	712.17	732.67	740.83
Variable costs				
Urea costs (US$ ha^{-1})	0	37.5	75	113.33
Fertilizer application (US$ ha^{-1})	0	15	15	15
Total variable cost (US$ ha^{-1})	0	52.5	90	128.33
Net benefits (US$ ha^{-1})	512	659.67	642.67	612.50
Marginal rate of return (%)		281	45	79

meter square and grain yield (Table 1). Grain yield and yield components were not significantly affected by row spacing (Table 1). Although, not statistically significant, row spacing at 0.75×0.10 m, the highest plant density generally, showed a better trend for higher grain yield and yield components than the lowest plant density (Table 3).

Averaged across years and plant density, increasing N levels did not have significant effect on kernel weight (Table 3). Averaged over years and plant densities, number of kernels per square meter and grain yield increased with N level with significant linear and quadratic responses (Table 3). On average, increase in N levels beyond 40 kg ha^{-1} did not result in significant increases in grain yield. Application of the first 40 kg N ha^{-1} resulted in the highest mean grain yield increase when compared to the yield increases obtained from the application of 80 and 120 kg N ha^{-1}. Across years and plant density, mean increase grain yields as a result of 40 kg N ha^{-1} applied over the control treatment was 39%. Doubling N application level to 80 kg ha^{-1} resulted in grain yield increase over control by 43%. Increasing N application level to 120 kg ha^{-1} resulted in yield increase over control by 45%. Nitrogen level and plant density did not affect harvest index (data not shown). Grain yield was positively correlated with number of kernels per square meter (r = 0.92) and kernel weight (r = 0.32). Grain yield also was correlated with chlorophyll concentration (r = 0.52), NUE (r = 0.59) and LAI (r = 0.87).

Nitrogen use efficiency: Nitrogen Use Efficiency (NUE) calculated as a ratio of grain yield to amount of N applied was not affected by plant density when averaged across years and N levels (Table 1). However, NUE decreased as linear function of N rate, regardless of plant density (Table 3). Sorghum had highest NUE (15.9 kg grain kg^{-1} N) at 40 kg N ha^{-1}. The use of 80 or 120 kg N ha^{-1}, however did not result in a corresponding increase in NUE across years. On average, the 120 kg N ha^{-1} resulted in the lowest NUE value of 5.9 kg grain kg^{-1} N (Table 3).

Economic analysis: The results of the economic analysis (partial budgets) for fertilizer N levels are presented in Table 4. In increasing order of total costs that vary, the fertilizer N levels could be ranked as 0, 40, 80 and 120 kg ha^{-1}. All treatments had positive gross benefits across years and row spacing. Fertilizer N levels (40, 80 and 120 kg N ha^{-1} levels) gave gross benefits that were greater than those of the control (0 kg N ha^{-1}). The net benefits ranged from 512 to 659.67 US$. Averaged across years and plant densities, the 40 kg N ha^{-1} gave the highest net benefits whereas the control gave the lowest net benefits. When compared to 40 kg N ha^{-1} treatments, the 80 and 120 kg N ha^{-1} levels had less net benefits but more total variable cost compared to 40 kg N ha^{-1} (Table 4). The Marginal Rate of Return (MRR) between no fertilizer treatment (farmers' practice) and 40 kg N ha^{-1} was higher than that of 80 and 120 kg N ha^{-1} treatments. It is apparent that changing from zero N treatment (farmers' practice) to 40 kg N ha^{-1} then to 80 kg N ha^{-1} and finally to 120 kg N ha^{-1} in that order gave positive MRR of 281% for only the change from zero N treatment to 40 kg N ha^{-1}. Across years, the MRRs for changing from 40 kg N ha^{-1} to 80 and finally to 120 kg N ha^{-1} were negative.

DISCUSSION

Low organic C and N contents of the soils in the Guinea savanna zone could be attributed to low vegetation cover and annual bush burning prevalent in many farming communities in the Guinea savanna zone of West Africa (Rhodes, 1995) Subsistence sorghum production in the zone is characterized by low external input, low crop yield, nutrient mining and land degradation. Thus, continuous sorghum production on savanna soils with low levels of organic C and N will be limited in the absence of fertilizers. Without fertilizer, sorghum yields will rapidly decline to the point that the farmer must abandon the field to a long-term fallow. Fertilizer N management practices on the fields of West African farmers should be improved if losses of soil organic N and organic matter are to be curtailed and stabilized in the short run.

Averaged across years and N fertilizer levels, grain yield was similar among row spacings, which is in agreement with finding of several studies (Gomase *et al*., 1987; Ma *et al*., 2003; Aflakpui *et al*., 2005), but contrasts with results of others (Huda, 1988; Ogunlela and Okoh, 1989; LaFarge and Hammer, 2002). Although, not statistically significant, sorghum planted at the highest plant density (133300 plants ha^{-1}) tended to grow taller, produce higher leaf area index and also flower earlier than those planted at the lower densities, but this did not influence grain yield significantly. Increased plant height as a result of high plant density possibly may be a response to lower light level and greater competition for light. Additionally, delayed flowering in low plant densities suggest that crop development and harvest may be delayed in decreased stand densities. Sorghum planted at different plant densities produced similar number of kernels per square meter and grain yields across years even though there were significant differences among final plant densities. Increases in kernels per panicle and in kernel weight may help compensate for low plant populations or limited tillering. Conley *et al*. (2005) observed that in uniform stands grain sorghum was able to partially compensate for low plant densities by producing additional grain heads per plant. As a result of this compensatory power, grain yield in cereals is relatively insensitive to plant population (Anderson, 1986); however, this compensation is less than perfect in grain sorghum (Kiniry, 1988).

Averaged across years and plant density, the application of N to sorghum, regardless of row spacing, increased early seedling vigor, LAI, leaf chlorophyll concentration and plant height but reduced the time to flower by 5 days. Early seedling vigor is critical to maximize nutrient uptake and efficient utilization. Nitrogen effects on LAI mainly result from a higher number of tillers and to a lesser extent from an increase in leaf area per tiller (Spiertz and De Vos, 1983). Stunted growth and N stress was visually observed on unfertilized plants which also recorded lower chlorophyll concentration (i.e., lower SPAD values) than fertilized plants. The leaves of sorghum plants that did not receive fertilizer N were light yellowish-green; plant growth was slow and flowering was delayed. When N supply is limiting, leaves become the main source of remobilized N to the grain. Chlorophyll concentration reduction and leaf yellowing are good indicators of N remobilization (Dwyer *et al*., 1995) and this could reduce grain yield. The importance of N fertilizer in improving soil fertility status and sustainable sorghum production is demonstrated clearly in the increased grain yield recorded across the two years. Sorghum produced lower biomass and grain yields and fewer kernels per square meter on the control plots (0 kgN ha^{-1}) than on N fertilized plots. Radiation interception was not measured in this study, but it is likely that the proportion of incoming radiation intercepted was very low with the control treatment due to reduced plant growth and leaf area development.

Rainfall was slightly below the long-term average in 2007, but was above the long-term average in 2008. However, there was no significant year × nitrogen interaction effect to indicate that response of grain yield and NUE to N fertilizer depended on rainfall amounts. Observed higher grain yield increases with the application of 40 kg N ha^{-1} when compared to 80 and 120 kg N ha^{-1} levels meant that the first 40 kg N ha^{-1} was probably adequate to meet the N requirements of sorghum in this zone. This apparently resulted in improved rooting depth, leaf area expansion, nutrient availability and uptake as well as increased N use efficiency, which optimized grain yield and net benefits. This is consistent with results of other studies (Ogunlela and Okoh, 1989; Buah *et al*., 1998; Lehmann *et al*., 1999; Khosla *et al*., 2000; Workayehu, 2000; Yamoah *et al*., 2002; Aflakpui *et al*., 2005; Conley *et al*., 2005). Differences in N use efficiency were related to grain yield response to applied N.

Results of the study showed that the 80 and 120 kg N ha^{-1} levels obviously added to the cost of production, but did not add significantly to output. This is evidenced by the fact that the main effect of increasing N level from 40 to 80 or 120 kg N ha^{-1} did not result in corresponding increase in grain yield, economic benefits or N use efficiency to merit the extra cost that may be incurred. Thus, maximum economic grain yields for sorghum occurred at fertilizer N level of about 40 kg N ha^{-1}. As a guide MRR of below 100% is considered low and unacceptable to farmers (CIMMYT, 1988). This is because such a return would not offset the cost of capital (interest) and other related transaction costs while still giving an attractive profit margin to serve as an incentive. Thus, the change from farmers' practice to the application of 40 kg N ha^{-1} which gave more than 100% MRR is a promising new practice for resource-poor farmers in the Guinea savanna zone.

Number of kernels per square meter was the yield component most associated with grain yield changes with N application in both two years. These results are generally consistent with those of (Maman *et al*., 2004), although they found kernel weight to have a higher correlation with yield than kernels m^{-2}. Grain yields were correlated with SPAD values (at flowering) suggesting that leaf N sufficiency level occurred with fertilizer application and this probably led to maintenance of leaf photosynthesis resulting in better grain filling.

In general, application of N fertilizer will be effective in terms of crop utilization and sustainable productivity. Results of this study demonstrated that using fertilizer N on sorghum was economically attractive. In this zone, soil fertility depletion is already high, relatively small amount of crop residues and animal manures are produced, hence mineral fertilizers will become the principal sources for building up nutrients in soils.

Shortcomings of past soil fertility research in this zone include limited economic analysis of results and use of trial sites and management that poorly represented those of smallholder farmers. The soil used for this study is a typical upland soil used for sorghum production in the Guinea savanna zone of West Africa. As no earlier study had been done in the area, a blanket fertilizer-N recommendation of 64 kg N ha^{-1} was being advocated by extension workers to farmers. This recommendation was based on experiment station results on maize and is even more than two decades old and not specific to any agro-ecology system. Resource poor farmers can rarely afford this recommended N level as most of them do not use N in sorghum production. The high cost and unavailability of fertilizers require that the limited amounts that are available must be used judiciously for maximum benefit. From this study, application of 40 kg N ha^{-1} to sorghum in this zone is economically attractive regardless of plant population (between 53300 and 133300 plants ha^{-1}). This level is less than the currently recommended N level for the production of improved sorghum varieties.

The study helped to identify agronomic practices and economic N level that should result in reduced economic risk and increased fertilizer adoption by sorghum farmers in the Guinea savanna zone. However, continuous use of N fertilizers, especially sulphate of ammonia can acidify soil which then requires liming when organic inputs are limiting. Thus, adequate soil fertility for sustained crop yields in this zone should be obtained through the combined and efficient use of mineral and organic fertilizers, the control of soil loss by erosion and crop residue restitution in adapted cropping systems.

CONCLUSIONS

The results, therefore, suggest that it is not necessary to consider plant density (> 53300 plants ha^{-1}) in determination of optimum N level for sorghum. Plant density did not affect sorghum response to applied N. Nonetheless, grain yield response to applied N and the optimum N application levels are generally similar for the range of plant densities tested. Thus, application of fertilizer N would increase sorghum grain yield and sustain soil fertility in the Guinea savanna zone. The practice will ensure food security; reduce nutrient mining and environmental degradation. From the range of N levels tested against the farmers' practice (0 kg N ha^{-1}), 40 kg N ha^{-1} gave an economic yield response and also sustained acceptable returns. Raising the N level to 80 or 120 kg N ha^{-1} did not result in corresponding increase in grain yield, economic benefits nor nitrogen use efficiency to merit the extra production cost that may be incurred. Fertilizing sorghum with 40 kg N ha^{-1} in dry land environment in the Guinea savanna zone, regardless of plant density (between 533000 and 133300 plants ha^{-1}) will give economic grain yields and result in reduced economic risk. The results can be used to make tentative recommendations in designing local credit program for resource- poor sorghum farmers in the region.

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