Tillage and Fertilizer Effects on Maize Production in Northern Guinea Savanna of Ghana

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Résumé

Buah, S. S. J. & Abatania, L. N. *Le labour et les Effets d'Engrais sur la Production de Maïs dans la Savane de Guinée du Nord du Ghana.* Le maïs (*Zea mays* L.) est une culture vivrière impotante au Ghana mais le rendement du grain est souvent limité par la fertilité du sol faible et les déficits de l'eau au cours du remplissage du grain. La réaction du maïs aux traitements du labour et d'engrais a été évalué dans un essai du champ de 2000 à 2002 sur un terreau sableux (Typic-plinthic Paleustalf) à Wa dans la savane de Guinée du Nord du Ghana. Le billon cloisonné en 4 semaines après la plantation sur le plat a été comparée avec la plantation sur une surface de sol plat sans billon et la pratique billon traditionnel 4 semaines après la plantation sur le plat en combinaison avec quatre traitements d'engrais (F1 ne = pas d'engrais F2 = 45-19-19; F3 = 64-38-38 et F4 = 90-38-38) comme kg N, P_2O_5 et K_2O ha-1. Labour induite par les différences dans la croissance de maïs et de rendement n'étaient pas significatifs en toute saison. Au fil des ans l'engrais a augmenté la croissance de maïs et de rendement, mais c'était indépendant du traitement labour**.** La moyenne de rendements du grain avec le F2, F3 et F4 traitements étaient 208-234, 304-413 et 391-567 % plus qu'avec l'absence de traitement d'engrais, respectivement. Le rendement de résidus moyenne était de 74-85, 147-158 et 131-141 % supérieur respectivement, avec F2, F3, F4 qu'avec aucun traitement d'engrais. Les analyses économiques qui ont montré le taux de rendement marginal dans l'application d'engrais allant de 97 à 107 %. Le MRR de F3 était supérieure à celle de F4 mais F4 a eu plus de rendements nets. Études complémentaires peuvent être nécessaires pour établir le moment opportun de niveau d'engrais de billon cloisonné et optimale pour le maïs dans la savane de Guinée du Ghana.

Mots-clés : Maïs, engrais, le billon cloisonné, zone de savane, rendements nets.

Abstract

Maize (*Zea mays* L.) is a major food crop in Ghana but grain yield is often constrained by low soil fertility and water deficits during grain fill. Response of maize to tillage and fertilizer treatments was evaluated in a field experiment from 2000 through 2002 on a sandy loam soil (Typic-plinthic Paleustalf) in Wa in the northern Guinea savanna of Ghana. Tied-ridging at 4

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wk after planting on the flat was compared with planting on a flat soil surface without ridging and with a traditional ridging practice 4 wk after planting on the flat in combination with four fertilizer treatments (F1 = no fertilizer; F2 = 45-19-19; F3 = 64-38-38 and F4 = 90-38-38) as kg N, P_2O_5 and K_2O ha^{-1}. Tillage-induced differences in maize growth and yield were not significant in any season. Over the years fertilizer increased maize growth and yield but this was independent of the tillage treatment. Mean grain yields with the F2, F3 and F4 treatments were 208-234, 304-413 and 391-567% greater than with no fertilizer treatment, respectively. Mean stover yield was 74-85, 147-158 and 131-141% greater respectively, with F2, F3 and F4 than with no fertilizer treatment. Economic analyses showed that the marginal rate of return in applying fertilizer ranged from 97 to 107%. The MRR for F3 was greater than that of F4 but F4 had greater net returns. Further studies may be needed to establish appropriate time of tied-ridging and optimum fertilizer level for maize in the Guinea savanna of Ghana.

Keywords: Maize, fertilizer, tied-ridging, savanna zone, net returns.

Introduction

Maize (*Zea mays* L.) is a major food crop in Ghana but the soils of the major maize growing zone in northern Ghana are characterized by water deficits during grain fill and low levels of nitrogen (N) and phosphorus (P). Crop performance is much affected by the quantity and distribution of rainfall during the growing season. In the absence of adequate irrigation facilities, proper management of rainwater to ensure effective utilization of water and applied nutrients by the plant is essential in northern Ghana. Several farmers in the region grow maize on flat land or on mounds with little use of inorganic fertilizers and, because of insufficient soil moisture and low soil fertility, crop yields are often low. Other farmers plant on the flat and then ridge in about 4-5 wk after planting in order to prevent lodging of plants, waterlogging, weed infestation and also concentrate plant nutrients for better plant growth and development. Intense rainfall events before and after planting often result in considerable water loss from the field. The effect of soil water deficits on yield of maize may be alleviated by reducing runoff throughout the season by creating micro-catchments or microbasins, such as tied-ridging.

Growing crops in tied-ridges was introduced in West Africa in the 1950s (Anon, 1987). Tied-ridges typically consist of furrows from 0.20 to 0.30 m depth that are blocked with earthen ties spaced according to the slope of the land, soil water infiltration rate and expected intensity of rainfall. Research has shown that tied-ridges gave significant yield increases over the traditional farmers' practice of planting on flat land. Tied-ridging effectively reduced runoff and increased soil water storage in Tanzania (Macarthey *et al.*, 1971), the USA (Jones and Clark, 1987; Krishna, 1989), Burkina Faso (Hulugalle *et al.*, 1990), Zimbabwe

(Vogel, 1993). Sanders *et al.* (1996) estimated that the adoption of tied-ridging for small scale sorghum production in Africa increased farm income by 12%. In Burkina Faso, sorghum yields were greater with the combination of fertilizer and tied-ridges than with either fertilizer or tied-ridges alone (Nagy *et al*., 1990). Similar results were obtained for maize and sorghum (*Sorghum bicolor*) in Zimbabwe (Nyakatawa, 1996). Comparing ridges and flat bed configurations in the Guinea savanna of Nigeria, Kumar *et al.* (1987) concluded that overall system productivity was marginally greater in the ridge system, but that yield differences were not significant. However, Kanton *et al.* (2000) obtained significantly greater grain yield of sorghum with ridge seed bed compared with planting on flat land for manual, tractor and bullock tillage systems on sandy soils in northern Ghana.

The beneficial effects of tied-ridging on crop yield vary due to differences in amount and distribution of rainfall, soil type, slope, landscape position, crop and the time of ridging, with the most substantial effects in semiarid areas where high-intensity rainfall effects often result in significant runoff (McFarland *et al.*, 1991). Improper use of tied-ridging can result in problems such as ridge over-topping, ridge failure, water logging and total loss of the crop in severe storms (El-Swaify *et al.*, 1985; Jones and Clark, 1987). If the most intense and greatest amount of rainfall typically occurs during the growing season, it may be desirable to remove the ties at that time or tied-ridging may be inappropriate with such a rainfall pattern (Krishna, 1989). Vogel (1993) found that yields were more erratic with tied-ridging for a sandy soil in a semiarid environment due to lower soil water contents in the ridges during dry periods. Tied-ridging is expected to be most effective in increasing productivity in cases of continuous annual cropping with common occurrence of large early-season runoff events and soil water deficits during the growing season (Jones and Clark, 1987). Little information is available on the combined effect of tillage practice and fertilizer use on maize growth and yield in northern Guinea savanna of Ghana. The objective of this study was to determine the best combination of tillage treatments (flat, ridges, and tied-ridges) and fertilizer application rates for increased maize production on a savanna soil.

Materials and methods

The experiment was conducted during the cropping seasons (June - October) of 2000 through 2002 on the experimental farm of Savanna Agricultural Research Institute in Wa in the Upper West region of Ghana (10° 04' N ; 02° 30'W ; about 323 masl). The site is a semi-arid region, characterized by low, erratic, and poorly distributed unimodal rainfall, averaging about 1100 mm per annum. Most of the rain in this area comes as short duration high intensity storms between May and

October. Mean monthly temperatures during the growing season range from 26 to 30^{o} C (MSDG, 1997). The soil at the experimental site was derived from granite overlying Birrimian rocks and was sandy loam (Typic-plinthic Paleustalf according to the US soil Taxonomy) by texture and thus well to moderately well drained (ISSS-FAO-ISRIC, 1998). Soil test results indicated that the surface soil layer had 823 g kg^{-1} sand and 157 g kg^{-1} clay with a pH of 5.2 (1:1 H_2O), 0.82 g kg^{-1} organic C, 0.04 g kg^{-1} total N, 35.2 mg kg^{-1} exchangeable K and 11.04 mg kg^{-1} available P.

The treatments were applied to the same experimental units each year in a split-plot factorial arranged in three randomized complete blocks with three replications. Main plots were 8.9 by 25.6 m consisting of four subplots. Each 8-row subplot measured 8.0 x 6.4 m. The land was left fallow in 1999. The entire experimental area was tilled each year using tractor disc plough before imposing any of the treatments. Tillage treatments (flat, ridge and tied-ridge) were in the main plots and four fertilizer treatments (F1 = no fertilizer; F2 = 45-19-19; F3 = 64-38-38 and F4 = 90-38-38) as N, P_2O_5 and K_2O ha^{-1} in the subplots. The current fertilizer recommended rate for maize production in the savanna zone is 64-38-38 kg ha^{-1} as N, P_2O_5 and K_2O. The tillage treatments included the traditional practice of planting into a flat soil surface (flat planting), flat planting and tied-ridging at 4 wk later (tied-ridges) and the traditional ridging at 4 wk after flat planting (ridge treatment) using hand hoe. In line with the common traditional practice, the ridges were constructed at 4 wk after flat planting and were about 0.20 m in height. With the tied-ridges technique, ridges were made 4 wk after flat planting and the furrows tied at 1 m intervals using hand hoes to prevent water from flowing along the furrows.

An intermediate maturing maize cv. *Abeleehi* with a maturity classification of 105 days to physiological maturity was sown during the second week of June each year. The spacing was 0.80 m between rows and 0.40 m within rows with two plants per hill. Three seeds were sown per hill and thinned to 2 seedlings per hill at 2 wk after planting resulting in a target plant population of 62,500 plants ha^{-1}. All plots were weeded with hand hoe twice during the cropping season. Within 2 wk after planting, a basal NPK compound fertilizer (15-15-15) was applied to supply all the P and K to all plots except those with 0 kg N ha^{-1} rate. This basal compound fertilizer also supplied 19, 38 and 38 kg N ha^{-1} to the F2, F3 and F4 plots, respectively. A supplemental N as ammonia sulphate was applied 4 wk after planting to the respective plots to achieve the required N rates. All fertilizers were applied in a subsurface band about 5 cm to the side of the maize row.

Measurements included days to 50% silk emergence, plant height, grain yield, stover yield and 100-kernel weight. Plant height was recorded for 5 randomly selected plants in each of the central three rows at maturity by measuring the height from the ground to the tip of the tassel after ear emergence. Grain and stover yields were determined by harvesting the centre two rows of each subplot. Above ground biomass (stover) yield was based on samples dried to constant weight at 60^{o} C while grain yield was expressed at 150 g kg^{-1} water content. Seed weight was determined for a sample of 100 oven-dried kernels and harvest index was calculated as a ratio of grain yield to the above ground biomass yield on an air-dry weight basis. Leaf chlorophyll concentration of the second leaf from the top was assessed at 50% silk emergence 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 anthesis. Analysis of variance was conducted using SAS statistical software (SAS, 1988). Residual error variances were tested for homogeneity to determine if results from the seasons could be pooled into combined analyses. Treatment effects were considered significant at the 0.05 probability level. Also partial budget analysis was used to determine the net benefits of the fertilizer treatments and the marginal rate of return (MRR) to determine the benefits to farmers (CIMMYT, 1988). The MRR is the increased benefit of a treatment as a percentage of the increased cost.

Results and Discussion

Rainfall

Total precipitation for the growing season was 862, 616 and 701.5 mm in 2000, 2001 and 2002, respectively, as against a long term mean of 740 mm for Wa (MSDG, 1997). Total seasonal rainfall was considered typical in 2000, but the patterns of distribution differed among the three years (Table 1). Amount of rainfall in June was less than normal in 2002. July was relatively wet in 2002 but dry in 2001. Also, October was relatively dry in 2001 and 2002. Seasonal variation in the amount and distribution of rain was partly responsible for year differences in many of the parameters measured or calculated.

Table 1. Rainfall in June - October, 2000, 2001 and 2002, Wa, Ghana.

	Total amount of rainfall (mm)		
Month	*2000*	*2001*	*2002*
June	196.0	191.3	122.2
July	149.6	84.6	240.3
August	213.8	177.4	157.7
September	229.3	136.7	139.5
October	73.3	26.0	41.8
Total	862.0	616.0	701.5

Crop Performance

There was significant heterogeneity of residual error variances across years, hence, the data for each year were not pooled into combined analyses and are therefore presented individually. Over the years, tillage x fertilizer level interaction effects were not significant and the means for tillage and fertilizer levels were compared separately for each year. The lack of significant interaction between tillage treatment and fertilizer level suggest that the response of maize to fertilizer in tied-ridges made 4 wk after flat planting did not differ significantly from that in flat planting or ridging at 4 wk after flat planting.

Agronomic and physiological traits of maize measured or calculated in the experiment were not significantly influenced by tillage treatment in any season (Tables 2 - 4). However, performance for these and other crop growth traits tended to be generally superior for tied-ridging at 4 wk after flat planting as compared with flat planting and ridging at 4 wk after planting. Visually, maize grown on flat land without ridging was adversely affected by severe lodging, but lodging was reduced with ridging and tied-ridging at 4 wk after flat planting.

In general, crop phenology was significantly affected by fertilizer applications over the years. Time to 50% silk emergence was significantly reduced by fertilizer application in all seasons (Tables 2 - 4). Averaging over tillage treatment, the F4 treatment produced silk at least 1wk earlier than did unfertilized maize in all three seasons. The latest flowering occurred with unfertilized plants. Plant height was generally greater with fertilized maize than with unfertilized maize in all seasons and the height was about 2.0 m with the F3 and F4 treatments in 2001 (Table 3). Fertilized plants had greater chlorophyll concentration on a leaf area basis (i.e., greater SPAD readings - greener leaves) than unfertilized plants. Chlorophyll meter reading as a measure of N sufficiency was least with unfertilized plants and largest with fertilized plants, especially with the F3 and F4 treatments (Tables 2 - 4). Application of fertilizer to maize resulted in increased leaf area index (data not shown). The leaf area index which expresses the ratio of upper leaf surface to ground surface is a useful index of potential plant interception of radiant energy.

Stover yield

There were no significant differences among the tillage treatments for stover yield (Tables 2 – 4). In contrast, Nyakatawa (1996) reported that maize stover yield in 1.0 m tied-ridges was significantly greater than that on flat land in Zimbabwe, although the maize was planted in furrows of tied-ridges. Also, Kanton *et al*. (2000) reported that sorghum stove yield was greater in ridge

Table 2. Crop phenology, grain yield and yield components of maize as affected by tillage and fertilizer treatments in 2000 at Wa in the Guinea savanna zone of Ghana.

Treatment	*DFS*◆ *days*	*Plant height m*	*SPAD reading no.*	*100-kernel wt gm*	*Kernels per m²* *no.*	*Grain yield kg ha⁻¹*	*Stover yield kg ha⁻¹*	*HI kg kg⁻¹*
Flat	63	1.39	44.4	23.86	1151	3235	2520	0.47
Ridges	63	1.49	44.6	23.48	1177	3261	2708	0.46
Tied-ridging	63	1.46	45.2	23.75	1271	3501	2682	0.48
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer level								
F1◆◆	68	1.07	31.3	21.02	428	1022	1363	0.38
F2	62	1.53	45.5	23.64	1160	3148	2526	0.48
F3	60	1.58	50.2	24.42	1489	4127	3368	0.49
F4	60	1.60	51.9	25.72	1723	5031	3290	0.53
LSD (0.05)	1.0	0.09	2.1	1.34	161	546	277	0.03
CV (%)	2.0	6.0	4.9	5.7	13.6	16.6	10.6	7.5

◆ DFS: days to 50% silk emergence; HI: harvest index.
◆◆ F1: no fertilizer; F2: 45-19-19; F3: 64-38-38 and F4: 90-38-38 as N, P_2O_5 and K_2O ha^{-1}.

seed beds over their flat counterparts for different tillage systems on a sandy soil in the Upper East region of Ghana. In their study, seed was sown on ridges instead of the common traditional practice of ridging at 4 wk after flat planting.

Added fertilizer generally resulted in significant stover yields over no fertilizer applications. Stover yields were least with no fertilizer treatment and greatest with the largest fertilizer level. Mean stover yields with the F2, F3 and F4 treatments were on average 74 - 85, 147 - 158 and 131 - 141% more than with no fertilizer treatment, respectively. Mean stover yield was largest in 2000 and 2001 crop season compared to 2002 season. Stover yield was closely related to increasing fertilizer levels. The maize crop made good early growth in all seasons, as indicated by substantial stover yield. In the savanna zone where livestock is part of the production systems, stover production is valued because the stems are used for fuel and the leaves and stems are used as cattle feed during the long dry season.

Grain yield and yield components

Mean grain yield generally was largest in 2000 crop season compared to 2001 and 2002 (Tables 2 - 4). This could be attributed to appreciably greater rainfall over the growing period in 2000. There was less rainfall in 2001 and 2002 before the crop reached physiological maturity. Although the plants may have had continued access to deeper water, the effects of soil water depletion during the grain-fill period were reflected in small kernel size, less kernel numbers and small grain yield in 2001 and 2002. Additionally, very small grain yields in 2002 may be partly due to the

Table 3. Crop phenology, grain yield and yield components of maize as affected by tillage and fertilizer treatments in 2001 at Wa in the Guinea savanna zone of Ghana.

Treatment	*DFS*◆	*Plant height*	*SPAD*	*100-kernel wt*	*Kernels per* m^2	*Grain yield*	*Stover yield*	*HI reading*
	days	*m*	*no.*	*gm*	*no.*	*kg* ha^{-1}	*kg* ha^{-1}	*kg* kg^{-1}
Flat	66	1.73	42.4	21.24	830	2090	2773	0.43
Ridges	67	1.89	43.8	20.38	848	2101	2886	0.44
Tied-ridging	66	1.77	42.9	21.40	894	2224	2473	0.48
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer level								
F1◆◆	72	1.40	33.6	18.43	243	530	1420	0.43
F2	65	1.74	43.2	20.19	771	1772	2559	0.46
F3	65	2.01	45.3	22.00	1085	2717	3465	0.43
F4	64	2.04	50.2	23.40	1330	3535	3399	0.46
LSD (0.05)	2.0	0.12	2.2	1.50	151	473	540	NS
CV (%)	2.4	7.2	5.1	7.2	17.8	22.3	20.1	10.6

◆DFS: days to 50% silk emergence; HI: harvest index.
◆◆ F1: no fertilizer; F2: 45-19-19; F3: 64-38-38 and F4: 90-38-38 as N, P_2O_5 and K_2O ha^{-1}.

continuous annual cropping of maize.

Though seasonal differences due to variation in rainfall were marked, grain yield and yield components from tied-ridging 4 wk after flat planting was generally not significantly greater than that from planting on the flat or ridging at 4 wk after flat planting. Even in 2001 when there was limited growing season precipitation, there was still no significant yield response to tied-ridging as specified by Jones and Clark (1987). On average, the value of tied-ridge tillage at 4 wk after flat planting to water conservation and maize grain yield was marginal (6-8% more grain). The results are in agreement with the findings of Kumar *et al.* (1987). Similarly, Wiyo *et al.* (2000) concluded from their work in Malawi that tied-ridging is not likely to benefit a corn crop in coarse-textured

Table 4. Crop phenology, grain yield and yield components of maize as affected by tillage and fertilizer treatments in 2002 at Wa in the Guinea savanna zone of Ghana.

Treatment	*DFS*◆ *days*	*Plant height m*	*SPAD reading no.*	*100-kernel wt gm*	*Kernels per m^2 no.*	*Grain yield kg ha^{-1}*	*Stover yield kg ha^{-1}*	*HI kg kg^{-1}*
Flat	68	1.29	34.3	18.73	459	1065	1936	0.47
Ridges	68	1.25	34.3	17.43	475	998	1828	0.48
Tied-ridging	68	1.2	36.4	16.57	520	1071	1735	0.48
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Fertilizer level								
F1◆◆	72	0.97	23.1	15.94	162	309	960	0.44
F2	68	1.26	37.1	17.17	462	964	1671	0.52
F3	67	1.43	38.8	18.67	621	1388	2481	0.46
F4	66	1.40	41.0	18.52	692	1518	2222	0.50
LSD (0.05)	2.0	0.12	3.9	2.13	181	481	545	0.06
CV (%)	3.1	10.1	11.3	12.2	37.6	26.5	30.0	13.3

◆ DFS: days to 50% silk emergence; HI: harvest index.
◆◆ F1: no fertilizer; F2: 45-19-19; F3: 64-38-38 and F4: 90-38-38 as N, P_2O_5 and K_2O ha^{-1}.

soils regardless of the seasonal rainfall amount because most of the water is lost to internal drainage. On the contrary, Kanton *et al.* (2000) reported that in terms of grain yield, sowing on ridge is superior to sowing on the flat on sandy soils in the Upper east region of Ghana. Additionally, Nyakatawa (1996) and Hiremath *et al.* (2003) obtained significantly greater grain yield with tied-ridging compared with planting on flat land, although those studies were either with in-furrow planting on sandy soils or on vertic soils where internal drainage was likely to be slower than for sandy loam soils. Moreover in northern Ghana, tied-ridging at 4 wk after planting on flat may not have any yield benefits for maize in coarse-textured soils regardless of the seasonal rainfall amount. Furthermore in years with above-average rainfall, temporary water logging and leaching of nutrients could reduce the yields of crops under tied-ridging system. Whereas in years with very low and poorly distributed rainfall there may not be enough rainfall to cause significant concentration of water in the furrows at the times it is most needed by the crop.

Kernel number and 100-kernel weight in all years were least with no fertilizer treatment and greatest with the largest fertilizer level (Tables 2 – 4). The trend was consistent over the years. The value of greater plant nutrient availability with added fertilizer was reflected in kernel size that was 8 - 12, 16 - 19 and 16 - 27% greater with F2, F3 and F4 than with F1 treatment, respectively. More available nutrients for most of the season with added fertilizer than with no fertilizer treatment resulted in 171 - 447% more kernels per unit area. Increased kernel size and numerically more kernels due to fertilizer application resulted in greater grain yields.

Grain yields were least with no fertilizer treatment and greatest with the F4 treatment. On average, mean grain yields with the F2, F3 and F4 treatments exceeded those from no fertilizer treatment (F1) by 208 - 234%, 304 - 413% and 391 - 567%, respectively. Thus, moderate fertilizer levels resulted in large and consistent increases of maize yields over the years. Fertilizer effects on grain yields reflected fertilizer effects on yield components. Grain yield increases due to fertilizer application were more a function of kernel number (r = 0.98 - 0.98) rather than kernel size (r = 0.71 - 0.88). Chlorophyll content was associated with grain yield (r = 0.76 - 0.95) suggesting that leaf N sufficiency level probably occurred with fertilizer application which improved grain yield.

In this study, the largest rate of fertilizer was superior to the current fertilizer recommendation of 64 - 38 - 38 kg ha^{-1} as N, P_2O_5 and K_2O in all three seasons. The difference may be attributed to appreciably greater fertilizer N for the F4 treatment as the P and K levels for the two treatments were similar. The results suggest that the existing fertilizer recommendation (i.e., 64-38-38 kg ha^{-1} as N, P_2O_5 and K_2O) for maize in the Guinea savanna may not be the economic optimum rate and therefore needs to be updated.

Over the years, it was evident that sustained and economic grain yields would not be attained on this savanna soil by producers without fertilizer addition. The substantial increase in grain yield with inorganic fertilizer application confirms that low soil fertility certainly limits maize production on savanna soils. This agrees with the findings of Horst and Härdter (1994). Harvest index values were increased with increasing levels of fertilizer except in 2001. Greater harvest indices as a result of fertilizer application suggest that depending on the season, inorganic fertilizer may promote the production of more grain dry matter per unit of total dry matter produced by maize.

In this study, the positive effect of added fertilizer on maize grain yield was realized both in 2000 and 2001 which were wet and dry seasons, respectively. However, the responses were greatest in the wettest year (i.e., 2000). This agrees with the report of Nyakatawa *et al.* (1997) that the response of maize to fertilizer N is much affected by the quantity and distribution of rainfall during the growing season. Management practices to delay depletion of soil water may improve grain yield. Time of tied-ridging was not addressed in this study. Considering the timing of crop development, cessation of rainfall and soil water depletion, planting with the onset of the rains seems to be an opportunity to improve availability of water during grain fill and to increase kernel size and grain yield. Soil fertility improvement nonetheless, offers the best management option for increasing maize grain yield in the savanna zone.

Economic analysis

Partial budget analysis was used to determine the net benefits of the fertilizer treatment and the marginal rates of return (MRR) to determine the benefits to farmers (Table 5). Pooled results across years were analysed and actual yields were adjusted downwards by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment on their farms.

Partial budgeting for grain yield across seasons showed that fertilizer application gave marginal rate of return that was greater than the minimum acceptance level. For majority of situations the minimum rate of return acceptable to farmers will be between 50 and 100%. Farmers should be willing to change from one technology to another if the marginal rate of return of that change is greater than the minimum rate of return. In this case, a 50% minimum rate of return is a reasonable estimate for farmers who already plant maize without fertilizer and simply need to change to improved varieties with some fertilizer application. Although the MRR of 107% for T3 is greater than that of F4 (97%), the latter provides greater net returns (i.e., GH¢157.81 vs. GH¢171.20). The choice between the F3 and F4 treatments will depend on resource endowment of the farmers. The additional benefits associated with fertilizer application far exceeded the additional costs. The results suggest that money invested in fertilizer for maize production in northern Ghana would give good returns.

Table 5. Economic analysis of fertilizer treatments in 2000 to 2002 at Wa in the Guinea savanna zone of Ghana.

Fertilizer rate (kg ha^{-1})	F1◆	F2	F3	F4
Average maize yield (kg ha^{-1})	620	2027	2809	3230
Adjusted maize yield (-10%)	558	1824	2528	2907
Price of maize (GH¢ kg^{-1})	0.10	0.10	0.10	0.10
Gross benefits (GH¢ ha^{-1})	55.80	182.43	252.81	290.70
Variable costs				
NPK Fertilizer (GH¢)	0	32.50	65.00	65.00
Sulphate of Ammonia (GH¢)	0	24.25	24.25	48.50
Transporting fertilizer (GH¢)	0	0.50	0.75	1.00
Fertilizer application (GH¢)	0	5.00	5.00	5.00
Total variable costs (GH¢ ha^{-1})	0	62.25	95.00	119.50
Net returns (GH¢ ha^{-1})	55.80	120.18	157.81	171.20
Marginal rate of return (%)		103	107	97

◆ F1: no fertilizer; F2: 45-19-19; F3: 64-38-38 and F4: 90-38-38 as N, P_2O_5 and K_2O ha^{-1}.
Exchange rate at the time of the work : 1US$ = GH¢0.90.

Conclusions

In this study, the choice of any of the tillage systems tested is not very critical in determination of optimum fertilizer level for maize in the northern Guinea savanna. The results however, suggest that regardless of the seed bed type (flat land, ridges or tied-ridges) farmers in the northern Guinea savanna agro-ecology can get better returns to the money invested in NPK fertilizer for maize production than with their traditional practice of no fertilizer input. Fertilizing maize in dry land environment in the

Guinea savanna zone, regardless of the tillage system will give economic grain yields and result in reduced economic risk. The practice will ensure food security; reduce nutrient mining and environmental degradation. The results confirmed that low soil fertility is a more critical constraint to maize production in most years in northern Ghana.

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