Determining Optimum Fertilizer Rates for Cotton in Northern Ghana

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Received: February 2005 Accepted: January 2006

Resumé

Fosu, M., Chamba, E. B., Afuakwa, J. J. & Clottey, V. A. *Déterminer le niveau optimal de l'egrais pour le coton au nord du Ghana.* Les sols des zones principales de la culture du coton au nord du Ghana sont caracterisés par les niveaux bas de l'azote, du phosphore et des fois du potassium. La réaction du coton à l'engrais N.P.K. était étudiée à Nyankpala et Wa en 1991, 1993 et 1994 pour déterminer les niveaux économiques pour la culture du coton. Le coton a bien réagi aux N. P. et K mais on a remarqué une réponse différente en 1991 quand le K était uniquement appliqué à toutes les deux localisations. Les données des résultats en 1993 et 1994 a Nyankpala et Wa étaient ajustées aux fonctions régressives du deuxième ordre pour générer des courbes responsives pour les différents éléments nutritifs. L'optimum économique pour chaque élément était déterminé à partir d'une combinaison des premiers differetials des fonctions quadratiques et les rapports du prix du coton et les matériaux d'engrais. A Nyankpala, l'optimum éconimique à travers les années pour N, P et K étaient 53, 30 et 30 kg ha^{-1} respectivemet. Les valeurs respectives à Wa étaient 73, 38 et 37 kg ha^{-1} NPK. On recomande encore des éssais aux champs pour établir des courbes responsives valables et l'optimum économique pour chaque élément.

Mots clés: Le coton, la réaction du nutriment, le niveau économique, le nord du Ghana.

Abstract

The soils of the major cotton growing zones in Northern Ghana are characterised by low levels of nitrogen(N), phosphorus (P) and sometimes potassium (K). The response of cotton to NPK fertilizer was studied at Nyankpala and Wa in 1991, 1993 and 1994 to determine economic rates for cultivation of the crop. Cotton responded to N, P and K except for K at both locations in 1991 where K was applied alone. The 1993 and 1994 response data at Nyankpala and Wa were fitted with second order regression functions to generate response curves for the various nutrient elements. The economic optimum for each element was determined from a combination of the first differential of the quadratic functions and the price ratios of cotton and fertilizer materials. At Nyankpala, the economic optimum across years for N, P and K were 53, 30 and 30 kg ha^{-1} respectively. The respective values at Wa were 73, 38 and 37 kg ha^{-1} NPK. Further multilocational on-farm testing is required to establish reliable response curves and economic optimum for each element.

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Keywords: Cotton, nutrient response, economic rate, Northern Ghana.

Introduction

The cultivation of cotton started in Ghana around 1901 (Koli, 1973) but it was not until 1968 that commercial production became important with the formation of Cotton Development Board (CDB). The board supplied seed, fertilizer, tractor services and pesticides to the farmers and bought the seed cotton from the farmers at a fixed price determined solely by it. By 1976 some 24,000 ha was put under the crop. Upper East and Upper West regions were the major producing areas providing 52% of the total output with 12%, 22% and 14% being produced from Northern, Brong Ahafo and Volta regions, respectively. This increased production could not be sustained however. By 1984 the cotton industry had virtually collapsed with only 1,500 ha under cultivation. Total seed cotton production fell from 11,000 tonnes in 1976 to 250 tonnes in 1978 and yield declined from 1,000 kg ha^{-1} in 1971 to 200 kg ha^{-1} in 1984.

Many factors were responsible for this decline and the most important was the low prices paid to farmers. Most farmers were unable to obtain financial returns from cotton sales large enough to purchase the foodstuffs they would otherwise have produced. Other factors include reduction in the support services by the Cotton Development Board and lack of improved technologies necessary for increased production.

In 1985 CDB was turned private and became Ghana Cotton Company (GCC). With the formation of other cotton companies like Plantation Development Limited (PDL) and many others, the industry was revived with a concentration in the three northern regions (Northern, Upper East and Upper West).

The cultivation of the crop with the revival of the industry still followed the old contract farming system in which the cotton companies provided inputs like tractor service, fertilizers, seeds and insecticides to farmers and in turn bought the seed cotton at prices determined solely by them.

Seed cotton yield from farmers' fields averaged 500 kg ha^{-1}, which was considered low. The cotton companies supplied 2 bags of compound fertilizer NPK 15-15-15 and 1 bag sulphate of ammonia for 1 unit of cotton field of 0.5 ha to farmers. This amounted to 51-30-30 kg ha^{-1} NPK. The blanket cotton fertilizer recommendation for Ghana is: N = 44.7- 55.8 kg ha^{-1}, P = 33.7- 44.7 kg ha^{-1}, and K = 22.2 - 33.6 kg ha^{-1} (Koli, 1973). This recommendation is 20 years old and not specific to any agro-ecology.

Soil test levels for nitrogen and phosphorus are very low for northern Ghana (Adu, 1969, 1995; FAO, 1967; Fosu, 2003). The amount of K in soils of cotton growing areas ranges from 20 to

100 ppm and considered adequate for the crop. This assumption probably underlines the reference to NPK 20-20-0 as cotton fertilizer by some people when it was first imported into the country. The critical level of K for cotton ranges from 40 to 125 ppm depending on soil type (Hearns, 1981). Apparent K deficiency symptoms have been observed in many fields where the soil test level of K was well above the critical level (Weir *et al.*, 1988) and soils with K levels of 150 ppm have been shown to have yield response to applied K (Constable *et al*., 1994). It is possible, therefore, that the crop may respond as well to K application in Northern Ghana.

The high cost of fertilizers requires that maximum benefit should be derived from their use. Research is needed to assess the response of cotton to N, P and K and to determine the most economic rates to apply within the responsive range. The objectives of this research were to determine the response of cotton to NPK fertilizers and to determine the most economic rates to apply in Northern Ghana.

Materials and methods

In 1991 fertilizer N, P and K were tested at Nyankpala (N 09° 24.000′; W 000° 59.262′) and Wa (N 10° 04.154′; W 002° 29.102′) at two levels, 0 and 50 kg ha^{-1} in a 2^3 factorial experiment to determine the response of cotton to these elements. Composite soil samples were taken before land preparation, and analysed for texture (pipette method), total N (Kjeldahl distillation), available P (Bray-1), exchangeable K (NH_4^+Ac/AAS), organic carbon (wet oxidation) and pH (0.01 M $CaCl_2$, 1:2 w/v). The experimental areas were ploughed and harrowed with tractor-mounted disc plough in early June and planting was completed by 3rd week of June in 3.6 m x 10 m plots on Ferric Lixisols. Between six and ten seeds of ISA 205A cotton were planted and thinned to two plants per hill two weeks after planting. The full rates of P and K and half rate of N were applied soon after thinning and N topdressed at maximum squaring on September 1. The plots were weeded when necessary and pests were controlled by spraying Dursban (Chlopyrifos) and Karate (synthetic pyrethroid) every two weeks starting at beginning of squaring. The two middle rows were harvested for yield assessment.

The experiment was redesigned during 1993-1994 at the two locations to determine the most economic rates of NPK to apply to cotton, taking into account the lack of interaction between the nutrient elements in the 1991 experiment. Except for fertilizer rates, land preparation, pest control and other cultural practices were the same as in 1991. Five levels of NPK were selected and for varying amounts of each element, fixed amounts of the other two were added. The levels of nitrogen were

0, 20, 40, 60, 80 kg ha^{-1} with fixed amount of 30 kg ha^{-1} of P_2O_5 and K_2O. The levels of P were 0, 15, 30, 45, 60 kg ha^{-1} with fixed amounts of 60 and 30 kg ha^{-1} of N and K_2O respectively. For K, the levels were 0, 20, 40, 60 and 80 kg ha^{-1} with fixed amounts of 60 and 30 kg ha^{-1} of N and P_2O_5, respectively. A treatment of 80-60-80 kg ha^{-1} NPK representing the highest levels of each element was included to look for interactions. Treatments were arranged in a Randomised Complete Block with 4 replications in Nyankpala and 3 replications in Wa. The plots were 3.6 m x 10 m in size. Thirty petioles from the youngest fully expanded leaves of the main stem of selected plants in each plot were taken at 2 weeks interval from the time of squaring. These were analysed for NPK concentration. The two middle rows were harvested for seed cotton yield assessment.

Calculations and statistical procedures

ANOVA was performed on yield and its components using STATPACK and means were separated using the LSD test. The yield data for 1993 and 1994 were fitted with second order regression equations to generate response curves for each element. The equations are of the form: $\hat{Y} = \beta_0 + \beta_1 F - \beta_2 F^2$ ... (1)
where $\hat{Y}$ = expected yield, β_0 = yield without fertilizer element, β_1 and β_2 are coefficients and F is the rate of fertilizer element. The most economic fertilizer rate was determined by differentiation of equation (1) which was equated to Marginal Product (MP).

$$\partial\hat{Y}/\partial F = \beta_1 - 2\beta_2 F = MP \quad ... \quad (2)$$

$$MP = \beta_1 - 2\beta_2 F = pf/py \text{ (price ratio)} .. (3)$$

pf = price of fertilizer, py = price of cotton. The most economic rates (Table 6) were determined by solving for F in (3) for each regression equation.

Results

Rainfall at Nyankpala was above long-term mean in 1991 and 1994 but lower than the long-term mean in 1993 though better distributed (Fig. 1). Levels of organic matter, total N, available P and exchangeable K were low at both locations (Table 1). In 1991 seed cotton yield was increased significantly by N and P application, but there was no response to K (p = 0.05, Table 2). The greatest response was to N and the least was to K at all locations. The mean increase in seed cotton yield above the control across locations where N was applied alone ($N_1P_0K_0$) was 83%. The mean increase above the control across locations was 40% where P was applied alone ($N_0P_1K_0$) and 16% where K was applied alone ($N_0P_0K_1$). Where N and P were applied together but without K ($N_1P_1K_0$), the increase in yield across locations was 126% and when all the three elements were applied ($N_1P_1K_1$), the yield increase above the control was 175% across locations. No significant nutrient interaction was observed.

The response of cotton to increasing rates of N, P and K for 1993 and 1994 is

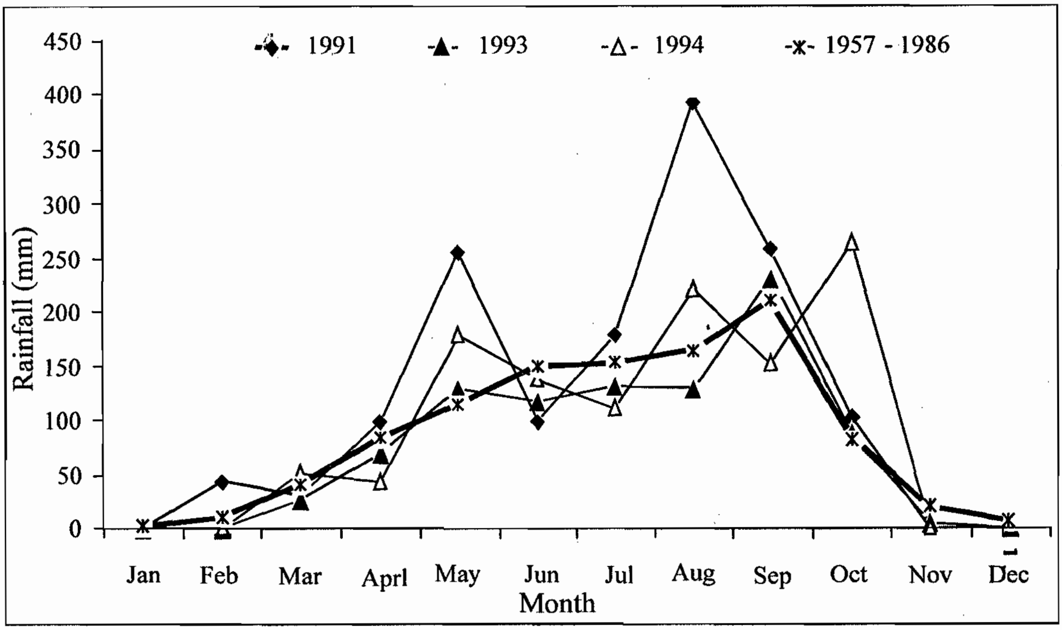


Figure 1. Rainfall at Nyankpala (long-term means of 1957 - 1986) and during the experimental years. Totals (Jan. - Dec.); 1991 = 1449.2 mm, 1993 = 936.5 mm.1994 =1155.1 mm, long-term (1938 - 1988) = 1034 mm.

Table 1. Physical and chemical properties of soils of the study areas in 1993.

Location	*pH*	*Particle size distribution*			*OM*	*Total N*	*Avail. P*	*Exc. K*
		Sand	*Silt*	*Clay*				
					%.		*mg kg^{-1}*	
Nyankpala	5.39	77.3	15.7	6.99	0.83	0.031	8.0	32.5
Wa	5.93	77.9	17.1	4.96	0.88	0.033	3.3	36.5

shown in Fig. 2 and Table 3, respectively. The yield response followed typical quadratic function, which was highly significant. At both locations, the highest depression of seed cotton yield occurred when N was not applied. Seed cotton yield was least depressed by absence of K application. In both years seed cotton yield in Wa was greater than in Nyankpala (Table 3 and Fig. 2).

The mean economic rates of NPK for Nyankpala and Wa across years (1993 & 1994) were 53-30-30 and 73-38-37 kg ha^{-1}, respectively (Table 4). For both years, the mean across locations was NPK 63-33-33 kg ha^{-1}.

Table 2. Effect of NPK fertilization on seed cotton yield at Nyankpala and Wa in 1991.

		Seed cotton yield (kg ha^{-1})			
		K_1		K_0	
		P_1	P_0	P_1	P_0
Nyankpala	N_1	1635.0a	948.3c-g	1388.3ab	1135.0b-f
	N_0	853.7d-g	843.3e-g	831.7fg	666.7g
Wa	N_1	1483.3a	783.4c-f	1183.3ab	950.0bc
	N_0	916.7b-e	516.7fg	816.7c-e	483.3g

N_0, P_0, K_0 = without N, P, K; N_1, P_1, K_1= with N, P, K. Means in each column followed by similar letters are not different at $p< 0.05$.

Table 3. Relationship between Seed Cotton Yield and levels of NPK applied at Nyankpala and Wa in 1994 as described by the equation: $ß_0 + ß_1F - ß_2F^2$.

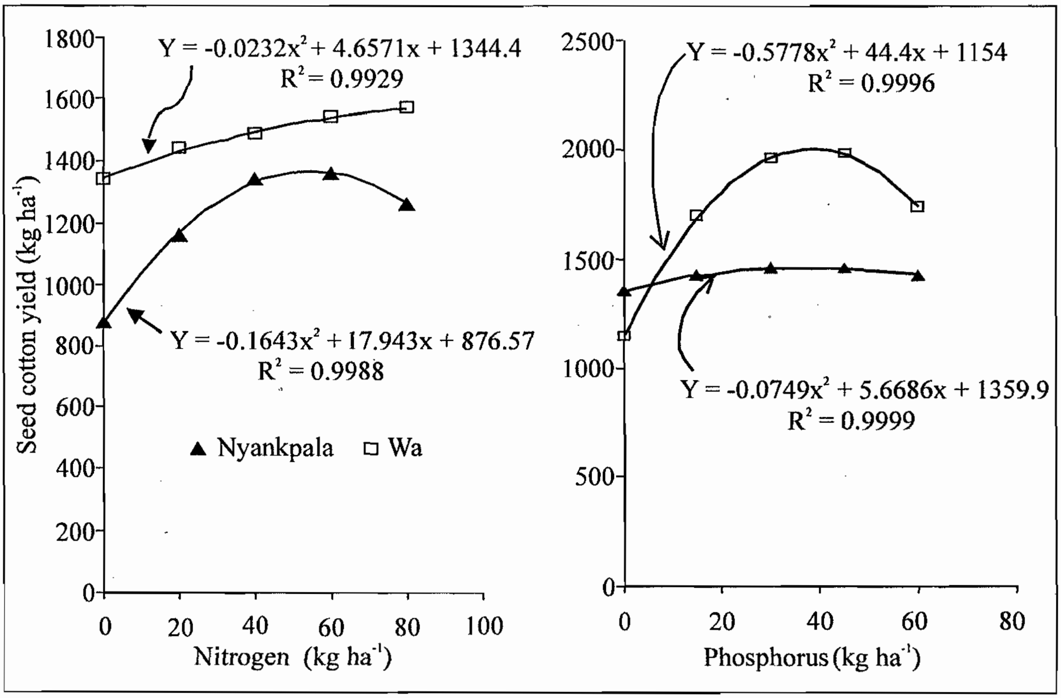
Location	Nutrient	Intercept ($ß_0$)	Coeff. ($ß_1$)	Coeff. ($ß_2$)	R^2
Nyankpala	N	1176	23.1	- 0.146	0.89**
	P	1673	26.8	-0.258	0.97**
	K	1759	23.4	-0.219	0.98**
Wa					
	N	1077	43.6	-0.393	0.96**
	P	1933	24.6	-0.311	0.76**
	K	2596	18.0	-0.194	0.79**

$ß_1$ and $ß_2$ are linear and quadratic coefficients, respectively, and F = rate of nutrient application. ** = significant at 1%.

Mean petiole N concentration measured in 1994 at maximum squaring (90 days after sowing) was 2.8%. This declined to about a third of this value 2 weeks later and remained so thereafter (Table 5). Mean petiole P levels were highest in early September (about 0.34 %) falling to approximately 0.15 % by October 15. The trend was also similar for K.

Discussion

The response of cotton to N, P and K at all locations underscores the need to apply fertilizers containing these elements. The fairly high yields of between 900 and 1400 kg ha^{-1} obtained in some control treatments may be attributed to residual effect of other crops or previous soil treatments. For



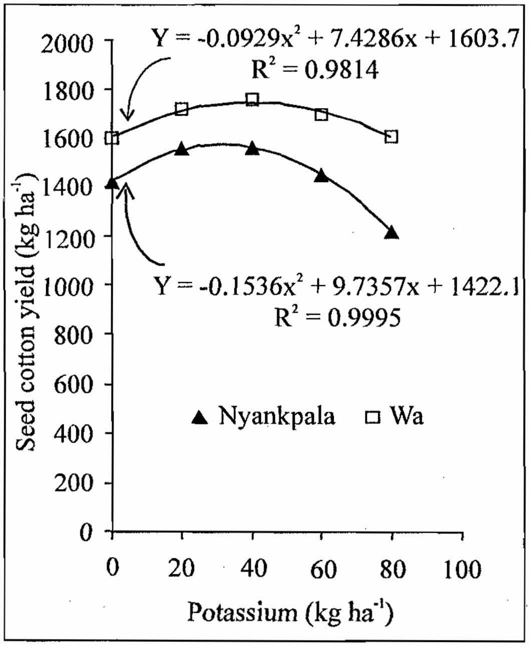


Figure 2. Response of cotton to NPK fertilization at Nyankpala and Wa in 1993.

example, at Nyankpala, the experimental area in 1993 was used for yam cultivation the previous year, following a legume crop in 1991. The residual effect of these crops might have affected the yield positively in the control treatment. At Wa the preceding crop in 1993 was groundnut.

The greatest response was to nitrogen indicating the importance of this element for cotton production in the growing areas as total N in soils of the area was below 0.05%. Ogunlela *et al.* (1986) found similar response to N when they applied the three elements to

Table 4. Economic optimum of NPK for cotton at Nyankpala and Wa for 1993 and 1994.

Location	*N (kg ha⁻¹)*		*P (kg ha⁻¹)*		*K (kg ha⁻¹)*	
	1993	*1994*	*1993*	*1994*	*1993*	*1994*
Nyankpala	52	54	30	28	27	33
Wa	76	70	37	38	33	41
Across loc	64	62	33.5	33	30	37

Table 5. Concentration of NPK in cotton petiole measured in September and October 1994 at Nyankpala.

	Petiole N (%)			
N (with P and K)	*Sept. 1*	*Sept. 16*	*Oct. 1*	*Oct. 15*
0	2.49	0.69	0.63	0.74
20	2.62	0.78	0.72	0.76
40	2.82	0.87	0.80	0.85
60	2.97	0.95	0.76	0.83
80	2.96	0.94	0.81	0.85
LSD (0.05)	ns	ns	ns	ns
P (with N and K)	*Petiole P (mg kg⁻¹)*			
0	3212b	1042b	1349b	1497a
15	3078b	1176b	1287bc	1574a
30	3693a	1410a	1716a	1454a
45	3543a	1372a	1618a	1542a
60	3665a	1433a	1193c	1628a
K (with N and P)	*Petiole K (mg kg⁻¹)*			
0	17637b	19907d	17798c	7495a
20	16656b	21595cd	16589c	8145a
40	19647a	22462c	16622c	8845a
60	22274a	26455b	21544b	8810a
80	21963a	34757a	26472a	8991a

Means in each column followed by similar letters are not different at $p < 0.05$.

cotton in Nigeria. However, care must be taken to avoid excess N application as this could result in lush, rank growth that attracts more pests and increases the problem of their control and the loss of mature bolls due to fungal rots (Matthews, 1989). Response of cotton to P was much lower at Nyankpala than at Wa (Fig. 2) due to the higher P soil test level at Nyankpala about 16 kg ha^{-1} compared to about 6 kg ha^{-1} at Wa. Though the response to K was low it is important to apply some K in these areas as cotton crops are net exporters of K (Constable *et al.,* 1994) and continuous cropping without K application could lead to depletion of this element in the soil. Déat (1973), cited by (IPI, 1976) reported a decline in the yield of cotton to 58% of the expected in 4 years when no K was applied with NPS to a soil which received an initial K of 60 kg ha^{-1}. Premature senescence of cotton has been linked to soils with marginal or deficient levels of K. The high mean petiole N concentration of 2.8% at 50% squaring (Sept. 1) with no significant differences between treatments indicated adequate flow of nitrate to the leaves even when no N fertilizer was applied. The sharp decline of petiole K level from adequate amount of 2 - 3% to deficient level (0.8%) coincided with heavy boll loading about mid October. Carpel walls of cotton bolls contain approximately 4% K and accounts for 60% of all the K accumulated by the plant (Weir *et al.,* 1988).

The economic optima of NPK for Wa were greater than those of Nyankpala. This could be explained by the greater yields obtained at Wa compared with Nyankpala. The reason for greater yields at Wa is not clear as the soil test levels for all nutrients analysed were similar. The less acid environment at Wa may have resulted in greater nutrient use efficiency to account for greater yield at this location. Fosu *et al.* (2004) reported greater apparent N recovery by maize in a less acid environment compared with one with higher acidity. Greater level of some nutrient other than NPK, e.g. sulphur or boron (not measured) might also be influencing the yield at Wa. Fosu and Chamba (1994) showed that fertilizer material containing 6% sulphur and 1% boron improved seed cotton yield above those without the two elements at Nyankpala.

The economic rates of fertilizer obtained were greater than the currently recommended rates being used by the cotton companies. Rapidly changing prices of fertilizers and seed cotton will alter the economic rates from year to year with the approach used. However, the regression functions may be used regardless of the price to arrive at economic optima periodically.

Further on-farm multilocational testing is required to arrive at reliable recommendations for farmers.

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