Evaluation of fertilizer application on some peasant cocoa farms in Ghana

M. R. APPIAH, K. OFORI-FRIMPONG & A. A. AFRIFA
Cocoa Research Institute of Ghana (CRIG), P. O. Box 8, New Tafo-Akim, Ghana

ABSTRACT

Low soil fertility has been identified as a major cause of decline in yield of cocoa (*Theobroma cacao* L.) on peasant farms in Ghana. The objective of the trial is to evaluate the effect of fertilizer application on yields of cocoa (*T. cacao* L.) under peasant farmers' management in Ghana with the aim of introducing fertilizers to farmers. This paper presents the results for 4 years of fertilizer trials on peasant farms. Triple or single superphosphate and muriate of potash at the rate of 129 kg P_2O_5 and 76.5 kg K_2O ha^{-1} yr^{-1}, respectively, were applied to one half of 1.6 -ha plot whilst the other half did not receive fertilizers. Generally, the fertilized plots on all the farms showed an increase in yield over the unfertilized plots during the 4-year period. The gross yields of the fertilized plots exceeded those of unfertilized plots by 61.7 per cent in the 1st year, 99.8 per cent in the 2nd year, 116.0 per cent in the 3rd year, and 106.0 per cent in the 4th year. At the end of the 4th year, 75 per cent of the farms had yields more than 1000 kg/ha. There were no significant differences between the age of the farms and variety of cocoa with fertilizer responses. Furthermore, there was no direct relationship between fertilizer treatment and incidence of diseases and pests. Substantial yields of over 1000 kg/ha could be obtained by adopting proper agronomic practices and the use of fertilizer compared to 280 kg/ha now produced in Ghana. Economic analysis of results indicated that the use of fertilizers on small-holder cocoa farms was profitable.

Original scientific paper. Received 6 Aug 99; revised 4 Oct 2000.

RÉSUMÉ

APPIAH, M. R., OFORI-FRIMPONG, K. & AFRIFA, A. A.: *Evaluation d'application d'engrais chimique sur quelques petits champs de cacao paysans au Ghana.* La fertilité basse du sol a été identifiée comme la cause principale de diminution en rendement de cacao (*Theobroma cacao* L.) sur les petits champs paysans au Ghana. Le but de l' essai est d'évaluer l'effet de l'application d'engrais chimique sur les rendements de cacao (*T. cacao* L.) sous l'exploitation des petits cultivateurs paysans au Ghana avec l'objectif de l'introduction des engrais chimiques aux cultivateurs. Les résultats pour les 4 années des essais d'engrais chimique sur les petits champs paysans sont presentés dans cet article. Le superphosphate triple et simple en plus de muriate de potasse à la proportion de 129 kg P_2O_5 et 76.5 kg K_2O par ha/an respectivement étaient appliqués à une demie de 1.6ha de lot alors que la demie autre n'avait pas reçu des engrais chimiques. Dans l'ensemble les lots fertilisés sur tous les champs montraient une augmentation en rendement par rapport aux lots non fertilisés pendant la période de 4 années. Les rendements bruts des lots fertilisés dépassaient ceux des lots non fertilisés par 61.7 pour cent dans la premiere année, 99.8 dans la 2^e année, 116.0 pour cent dans la 3^e année, et 106.0 pour cent dans la 4^e année. A la fin de la 4^e année, 75 pour cent des champs avaient plus de 1000 kg/ha de rendements. Il n'y avait pas des différences considérables entre les âges des champs et la variété de cacao avec l'engrais chimique en ce qui concerne les réactions. Par ailleurs, il n' y avait pas de rapport direct entre le traitement d' engrais chimique et le taux des maladies et les insectes ravageurs. Des rendements substantiels de plus de 1000 kg/ha pourraient être obtenu par l'adoption des pratiques agronomiques appropriées et l' emploi d' engrais chimique en comparaison de celui de 280 kg/ha produit à présent au Ghana. L' analyse économique des résultats indiquait que l'emploi d' engrais chimique sur les champs de cacao des petits cultivateurs était rentable.

Introduction

Fertilizer experiments on cocoa in Ghana did not begin until the mid-1950s when control measures against pests and diseases became effective. The earlier work has been reviewed by Cunningham & Arnold (1962), Cunningham & Smith (1961), Smith & Acquaye (1963), Acquaye & Smith (1965), Ahenkorah & Akrofi (1968, 1969), and Ahenkorah *et al.* (1981, 1987). The results indicated that shaded and unshaded cocoa responded to phosphate and potassium fertilizers, even though the responses were not very high; and that mature cocoa did not respond to nitrogen fertilizers. Young seedlings, however, responded to nitrogen.

Even though considerable data on response to fertilizers have been generated over the years at the Cocoa Research Institute of Ghana (CRIG), the impact of fertilizer use on the farmer has been very little. A survey conducted by CRIG in the cocoa-growing areas of Ghana showed that virtually no farmer in Ghana included fertilizer in his or her farm management programme. Charter (1953) emphasized that the peasant cocoa industry in Ghana had been based on the exploitation of the fertility built up by the forest, and that for cocoa established from virgin forest on fertile soils, fertilizers may not be required for many years. The rapid release of accumulated plant nutrients in the top few centimetres to the cocoa tree for the first few years, probably explained the low level of response of cocoa to fertilizers during the early years of these trials, since the trees were sited on relatively fertile soils. It is pertinent to note that plant nutrients which are removed annually from the cocoa farm through harvests adversely affect the fertility of the soil. Omotoso (1975) reported that the decline in yields of cocoa of about 17 years old was partly attributable to selection of bad sites and lack of fertilizer use in Nigeria.

Ahenkorah & Akrofi (1969) estimated the loss from an average annual marketable harvest of 400,000 tonnes dry cocoa beans at 16,000 tonnes of NPK nutrients. Urquhart (1955) reported that the amount of major nutrients removed annually from the soil by cocoa (yield of 560 kg/ha) in the beans were 13.5, 3.4 and 11.2 kg/ha of N, P and K, respectively. Ahenkorah & Akrofi (1967) showed that soil available phosphorus definitely declined after 10 years of continuous cropping of Amelonado cocoa at CRIG. At the end of the shade and manurial trial at Tafo, it was observed by Ahenkorah, Akrofi & Adri (1974) that there was a loss of about 54,800 kg humus/ha within a 15-year period of continuous cocoa cropping. Attendant to this was a total depletion of more than 66 per cent of exchangeable bases. Appiah *et al.* (1997) estimated the total amount of nutrients removed from exportable cocoa beans and pod husk over a 10-year period at over 232,000 tonnes.

Even though cocoa production in Ghana has increased over the last few years due to improved agronomic practices and increase in area under cultivation, the yield increase could be more substantial if fertilizer application was incorporated in the overall agronomic practices of the peasant farmers. A recent study conducted by the Ghana Cocoa Board Task Force in 1994 indicated that about 49.3 per cent of the farmers interviewed produced less than 256 kg/ha in the 1991/92 season, and 23 per cent produced between 256 and 384 kg/ha. Appiah *et al.* (1997) identified low fertility of soil as a major cause of the decline in yield on peasant farms, and suggested that to control deforestation in Ghana by cocoa farmers and to increase the yield per unit area on the peasant farms, fertilizers should be considered in any future cocoa production policy.

The objective of this paper, therefore, is to evaluate the effect of fertilizers on cocoa yields under peasant farmers' management in Ghana with the aim of introducing fertilizers to the farmers.

Materials and methods

Soils

The farms on which the trials were sited generally had soils classified as Rhodic Ferralsols (FAO/UNESCO Soil Map of the World, 1968). Twenty peasant farms located in the six cocoa-growing districts in Ashanti Region of Ghana were selected for the trial. During the pre-selection period, surface soil samples (0 - 15 cm depth) were collected, air-dried at room temperature, passed through a 2-mm sieve, and stored in polyethylene bags for routine chemical analyses.

Criteria for farm selection

Three criteria, namely farm maintenance, attitude of the farmer, and accessibility, were used in addition to soil analyses, in arriving at the final selection of the farms. The age of the farms ranged from 9 to 27 years.

Farm maintenance. Generally, at least a minimum level of farm maintenance, such as weeding, chupon and mistletoe removal, pest and disease control were initially practised by the farmer. All the oil palm trees in the farms were also removed. Shade manipulation was effected where necessary.

Attitude of the farmer. The farmer and the farm caretaker should be co-operative and be prepared to accept advice given by the research team. Attitude was ascertained from informal interview of participating farmers and caretakers.

Accessibility. The trials were sited on farms at vantage areas where other farmers could witness the results. The accessibility of the farms by motor road was also considered.

Design and layout

A 1.6-ha plot was demarcated from each farm and divided into halves along the slope. The number of cocoa trees in each half was recorded. Farm maintenance was the sole responsibility of the farmer under the supervision of the Extension Field Assistant in charge of the trials. Weeding was normally done at least 2 weeks before fertilizer application and subsequently as necessary.

Method and rate of fertilizer application

Triple or single superphosphate and muriate of potash thoroughly mixed were hand broadcast at the rate of 129 kg P_2O_5 and 76.5 kg K_2O $ha^{-1}yr^{-1}$ on one half of each plot between March and May each year just before the main rains whilst the other half did not receive fertilizer. Except for the cost of fertilizers and application which were borne by CRIG, all other expenses on farm operations were the responsibility of the farmer.

Data collection

The wide distribution of the experimental farms in the trial area and the continuous nature of data generation necessitated that the data collection be delegated to specially trained Field Assistants of the Extention Services Division, and special forms were designed for such purpose.

Pod categorization

The mature pods were harvested and classified into the 'good pods' which were the usable pods and the 'bad pods'. The 'bad pods' were predominantly black due to infection by black pod disease (*Phytophthora* spp.), but also immature ripe pods generally the result of *Bathycoelia thalassina* attack (Lodos, 1967) and other damaged pods. The plot yields were converted to a common number of trees per hectare for each farm and expressed as gross yield of kilogramme (kg) dry cocoa beans per hectare (ha), using a conversion ratio of 26 pods average, to 1 kg of dry cocoa beans.

Results and discussion

Tables 1, 2, 3 and 4, and Fig. 1 show the results of soil analyses and plot yields.

The data on the soil analyses (Table 1)

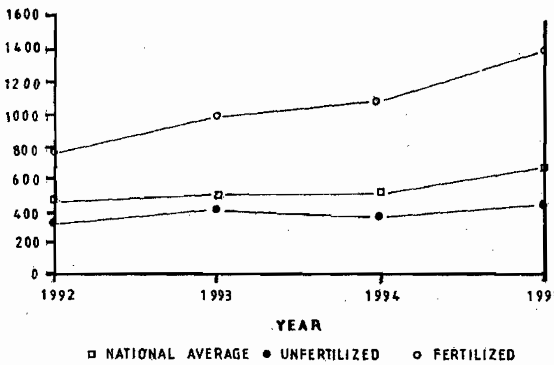

Fig. 1. The net yield of fertilized and unfertilized plots compared with estimated national yield.

TABLE 1

Some Physical and Chemical Characteristics of Soils of Farms Used in the Study

Farm no.	Texture	pH	% C	% N	Avail. P μg/g 0.2 NH_2O_4	K meq/100 g	Mg meq/100 g	Ca meq/100 g
1	Loamy sand	5.5	1.32	0.18	1.40	0.15	2.20	6.25
2	Loamy sand	5.8	1.29	0.21	1.60	0.02	3.50	8.65
3	Sandy clay loam	5.0	1.91	0.23	0.95	0.10	1.12	15.40
4	Sandy loam	5.9	1.61	0.18	1.75	0.00	3.15	17.65
5	Sandy clay loam	6.1	1.89	0.13	1.90	0.00	3.20	7.20
6	Sandy loam	5.5	1.39	0.12	0.95	0.15	1.60	4.15
7	Loamy sand	5.3	0.63	0.10	1.70	0.10	0.85	1.95
8	Loamy sand	6.0	0.58	0.08	1.50	0.10	0.85	1.95
9	Sandy clay loam	4.3	1.08	0.08	1.10	0.55	1.65	7.50
10	Loamy sand	6.0	1.03	-	0.45	0.30	1.28	7.65
11	Sandy loam	4.4	0.62	0.26	1.65	0.28	0.64	6.27
12	Clay loam	5.8	3.76	-	0.20	0.29	1.91	13.83
13	Sandy loam	6.3	2.21	0.37	0.80	0.30	2.75	12.20
14	Clay loam	5.1	1.23	0.15	1.20	0.25	1.95	4.05
15	Sandy loam	6.2	1.26	-	1.45	0.25	2.15	6.65
16	Sandy loam	6.3	1.26	0.13	1.25	0.35	2.25	13.80
17	Loamy sand	6.3	0.89	0.11	1.45	0.15	2.05	5.50
18	Sandy clay loam	6.4	2.45	0.20	36.75	0.15	0.16	5.95
19	Sandy loam	6.7	0.62	0.14	0.25	0.14	1.2	6.9
20	Sandy loam	5.5	1.03	0.13	1.20	0.12	1.8	6.1

indicated that the soils on those trial farms fell within the soil group potentially classified as suitable cocoa soils. However, the nutrient contents were lower than the threshold values for cocoa cultivation as a result of nutrient depletion by cocoa.

In all the trials, the fertilized plots showed an increase in yield over the unfertilized plots during the 4-year period (Table 2). During the 1st year of the trial, only 25 per cent of the total number of fertilized plots had yields exceeding 1000 kg/ha. However, the percentage increased to over 75 at the end of the 4th year. Farm 11 recorded the least yields during the trial period, even though the percentage response due to the fertilizer was the highest (Tables 2 and 4). This could have been due to poor farm management on this particular farm, confirming the general observation that basic agronomic practices were essential ingredients in any fertilizer programme on cocoa (Ahenkorah *et al.*, 1981, 1987; Cunningham & Smith, 1961). Thus, Farm 20 which experienced steady increase in yield due to fertilizer over the period also had a steady improvement in the agronomic practices such as number of weeding, pruning, and other farm sanitation methods by the farmer. Tables 2 and 4 clearly indicate that response to fertilizers by mature cocoa varied from site to site and with level of management practices.

When the means of the gross yields were compared, the fertilized plots exceeded those of unfertilized plots by 61.7 per cent in the 1st year, 99.8 per cent in the 2nd year, 116 per cent in the 3rd year, and 106 per cent in the 4th year (Table 3). The control plots generally showed a slight increase at the end of the 4th year. Pooled

TABLE 2

Estimated Yield of Fertilized and Unfertilized Cocoa Plots Over a 4-Year Period in Ashanti Region, Ghana

Farm no.	District	Age of farm (yrs)	Cocoa type	Gross yield (kg dry beans/ha) 1991/92 *A	1991/92 **B	1992/93 A	1992/93 B	1993/94 A	1993/94 B	1994/95 A	1994/95 B
1	Nkawie	23.00	Amazon	2434.09	1713.96	2184.66	1296.01	3156.65	1976.50	1638.56	1194.78
2	Nkawie	17.00	Hybrid	1078.58	806.17	1484.05	1062.58	1342.83	954.32	2121.46	1430.67
3	Nkawie	24.00	Amazon	1374.41	915.86	1845.68	901.61	1404.08	724.79	2505.13	935.33
4	Nkawie	13.00	Hybrid	211.59	182.53	793.26	218.28	280.96	177.16	826.92	631.81
5	Nkawie	16.00	Amazon	809.31	522.55	771.23	379.91	1220.09	433.52	1233.95	614.77
6	Juaso	27.00	Amazon	403.13	241.26	1497.39	763.91	1489.89	712.20	3242.97	1651.06
7	Juaso	17.00	Amazon/ hybrid	669.37	378.40	587.51	582.81	1027.21	552.56	914.81	240.88
8	Juaso	17.00	Hybrid	223.03	136.09	408.21	286.18	957.98	445.44	467.52	248.81
9	Jamasi	12.00	Hybrid	724.93	534.09	1162.16	518.66	2251.33	756.55	1983.38	795.58
10	Jamasi	21.00	Amelonado	835.09	608.12	763.25	664.58	1025.12	840.88	899.76	753.56
11	Jamasi	12.00	Hybrid	911.87	293.73	228.63	6.65	450.85	32.05	365.05	54.61
12	Antoakrom	26.00	Mixed	1015.91	550.00	1186.94	239.41	803.18	80.58	1104.84	334.57
13	Obuasi/Bekwai	15.50	Amazon	511.54	282.05	1183.57	763.82	912.30	480.06	1554.94	1163.63
14	Obuasi/Bekwai	15.00	Amazon	386.75	184.00	512.35	309.83	672.41	330.39	1188.56	678.11
15	Obuasi/Bekwai	20.00	Amazon	635.61	258.17	1027.21	484.43	676.54	228.49	2759.97	1274.50
16	Offinso	15.00	Hybrid	553.46	313.72	830.42	212.73	1421.22	270.47	1349.65	395.77
17	Offinso	21.00	Mixed	911.54	663.81	1021.74	311.85	972.39	331.20	1161.23	442.08
18	Offinso	15.50	Mixed	1580.12	1010.40	1585.73	715.91	1375.21	780.63	1363.05	810.68
19	Fumso	12.00	Hybrid	611.25	349.19	1050.09	500.73	555.22	157.43	1447.20	186.08
20	Fumso	9.00	Amazon	260.87	37.80	538.18	121.84	488.03	124.98	1017.24	360.45

* - Fertilized, by application of 129 kg P_2O_5 and 76.5 kg K_2O/ha/yr
** - Unfertilized

TABLE 3

Mean Gross Estimated Yields of Cocoa over a 4-Year Period

Treatment	Mean yield (kg dry beans/ha) Year 1	2	3	4
Fertilized	807.12	1033.11	1124.17	1457.31
Unfertilized	499.09	517.09	519.51	705.39
Difference	308.03*	516.03**	604.66**	751.92**
% over unfertilized	61.72	99.80	116.00	106.60
Pooled standard error	±146.57	134.17	177.88	192.81

Statistical significance; * = 5 % level; ** = 1 % level; df = 38
t.025, 38 = 2.026; t.005, 38 = 2.716

TABLE 4

*Estimated Cocoa Yield: *Percent Response of Fertilized over Unfertilized Plots*

	Seasons			
Farm no.	1991/92	1992/93	1993/94	1994/95
1	42	69	60	37
2	34	40	41	48
3	50	105	94	168
4	16	263	59	31
5	55	103	181	101
6	67	96	109	108
7	77	1	86	280
8	64	43	115	88
9	36	124	198	149
10	37	15	22	19
11	210	3338	1307	568
12	85	396	897	230
13	81	55	90	34
14	110	65	103	75
15	146	112	196	117
16	76	290	150	241
17	37	227	425	163
18	56	122	194	68
19	75	110	253	678
20	590	342	290	182
Mean	97	296	243	169

* % Response = 100 (F - Fo)/Fo
where F = Yield from fertilized plot
Fo= Yield from unfertilized plot

treatment statistical difference tests conducted on the means indicated that whereas the yield difference in the 1st year was significant at $P<0.05$, yield differences in the next 3 years were statistically significant at $P<0.01$ (Table 3). The absolute yield response indicated progressive decrease after the 2nd year and a comparatively sharp drop during the 4th year (Table 4). This low response at the 4th year would suggest probable building up of the fertility levels in these farms. The gradual increase in yield of control plots might be due in part to improved agronomic practices adopted by the farmers during the trial. The design of the trials was such that the trees in the control plots close to the demarcation line benefited from the fertilizer application to the treated plots, as those trees were observed to carry heavy loads of cocoa during the period. This might have contributed to the increase in yield of the untreated plots. Since one of the objectives of the trial was demonstrative, very simple experimental layout which will not confuse the farmer was, therefore, adopted. Most of the farmers practised the CRIG-recommended packages for pest and disease control and shade reduction (manipulation). Ahenkorah *et al.* (1981) observed that optimum and sustained yield is associated with reduced overhead shade, which in turn dominates other ambient factors.

Table 4 indicates the percentage responses over the control. There was significant response of cocoa to fertilizer application over the 4-year period. The percentage responses observed in this trial were higher than those reported by earlier workers in Ghana. Results of demonstration experiments on peasant farms by Quartey Papafio & Edwards (1961) showed that increases in yield of up to 34 per cent could be obtained from fertilizer application. Ahenkorah & Akrofi (1969) found that seasonal responses to fertilizer (P and K) averaged 48 per cent. This observation confirms the assertion that prolonged cocoa cultivation results in the depletion of soil nutrients and higher responses to fertilizer application, and that cocoa established in virgin forest with high fertility soils show little response to fertilizers in the initial years (Charter, 1953).

During the 1992/93 and 1993/94 seasons, virtually no proper farm practices were applied on Farm 11, despite repeated promptings of the farmer. The unusually high percentage response observed on Farm 11 was due to the very low yields from the unfertilized plots relative to those from fertilized plots as a result of the farmer's poor agronomic practices (weeding, spraying, etc).

There were no significant relationships between the ages of the farms and varieties of cocoa with fertilizer responses. The relatively high yields for Farm 10 (Table 2) show that the yielding potential of Amelonado, which was previously estimated by Adams & Kelvie (1955), could be very much higher even after 25 years of cultivation and with fertilization. Even though Farm 6 had the oldest Amazon trees, it yielded over 3000 kg/ha at the end of the 4th year with fertilizer application (Table 2). This observation supports the report by Ahenkorah *et al.* (1987) that 20-year-old Amazon cocoa trees without fertilizer application in Ghana might have long passed their economic-bearing age.

The percentage of diseased pods was generally higher on the fertilized plots, although the differences between percentages of fertilized and control plots and seasons were not statistically significant. This agrees with the observation by Ahenkorah *et al.* (1987) that there was no direct relationship between fertilizer treatment and incidence of pest and black pod disease. However, Campbell (1984) showed that incidence of the mealybug *Planococus citri* increased with increasing nitrogen and decreased with increasing potassium on heavily shaded trees where the ant *Crematogaster africana* was dominant.

Fig. 1 shows the comparison between the estimated national yield average and the yield average of the experimental farms over the 4-year period. The national average yield was estimated from data on national production and the area under cocoa cultivation during the 4-year period. Whereas the estimated national average yield at the end of the 4th year was about 500 kg/ha, the average yield of the experimental farms from the fertilized plots was over 1300 kg/ha. It may be emphasized that the present increase in the country's cocoa production was not necessarily due to increase in productivity of the farms, but rather due to increase in the area under cultivation (Ahenkorah & Appiah, 1996).

The 'real' average yield of 280 kg/ha obtained in Ghana had been very low as compared to those obtained in Côte d' Ivoire, Malaysia, Brazil, and Indonesia (Report ICCO, 1992). Yield increases could be substantial by adopting proper agronomic practices and using fertilizers (Fig. 1). However, Cunningham & Arnold (1962) observed that at Tafo, the application of basic cultural practices on Amelonado cocoa without the use of fertilizer resulted in an average yield of more than 1000 kg dry cocoa/ha (range 675-1183) for 9 consecutive years on sites of relatively high fertility.

It is also important to consider fertilizer use from the standpoint of nutrient restoration and sustainable production of cocoa. Improvements in other agronomic practices alone will put further pressure on soil nutrient reserves which will later result in lower yields. In the past, low yields from cocoa farms might not have taxed the soil nutrient reserves too much at the farmers' level of cultural practices. However, the expected increase in production due to improvements in agronomic practices could rapidly deplete these reserves if no precautions are taken. Ahenkorah & Akrofi (1968) showed that soil available P was depleted after 10 years of continuous cropping of Amelonado.

The positive yield responses of the experimental farms due to fertilizers indicate that the absence of adequate essential plant nutrients is one of the major underlying causes of yield decline of cocoa farms in the Ashanti Region over the last years, and that most farms which have lost their original soil fertility could be greatly restored to their producing capacity with fertilizers. If the results from the trials are extrapolated on a national scale, national production could easily be more than doubled if fertilizer use forms a part of any agronomic package. One of the problems met with farmers in the trials was how to dispel the wrong idea that fertilizers could be a substitute for good management practices. Certainly, to derive the maximum benefit from fertilizers, great attention must be paid to general maintenance and pest and disease control.

One question which might be raised is whether counts of mature harvested pods could adequately express the yield effects of fertilizer or whether there are other effects on bean numbers, bean weight, etc. However, from the observations of participating farmers, fertilizer use improved the physical condition of the trees in terms of healthy leaves, profuse flowering and cherelles, and larger pods. Work is in progress to elucidate on these and other bean quality issues which might be associated with fertilizer use. Even though fertilizer use resulted in substantial yield increase, the increase should be economically viable before the peasant farmer would be attracted to adopt fertilizers in cocoa cultivation in Ghana. Economic analyses of the results showed that the use of fertilizer on small-holder cocoa farms was profitable. The levels of marginal benefit cost ratios (MB/C) averaging 3.65 and marginal rates of return (MRR) averaging 2.65 per cent per hectare showed a high probability that small-holder cocoa farmers in Ghana would adopt fertilizer use technology regularly if suitable fertilizers for cocoa become available on the market. Details of the economic analyses of the trial will be published elsewhere.

Acknowledgement

The authors are grateful to Technical Assistants of the Soil Science Section of the Cocoa Research Institute of Ghana (CRIG) and Extention Officers of the Cocoa Services Division (CSD) of Cocoa Board. This paper is published with the kind permission of the Executive Director of CRIG.

REFERENCES

Acquaye, D. K. & Smith, R. W. (1965) Effects of ground covers and fertilizers on establishment and yield of cocoa on clear felled land in Ghana. *Expl Agric.* **1**, 131-139.

Adams, S. N. & Mc Kelvie, A. D. (1955) Environmental requirements of cocoa in the Gold Coast. *Rep. Cocoa Conf. Lond.* pp. 22-27.

Ahenkorah, Y. & Akrofi, G. S. (1968) Amazon cocoa (*Theobroma cacao* L.) Shade and manurial experiment (K2-01) at the Cocoa Research Institute of Ghana. I. First five years. *Agron. J.* **60**, 691-694.

Ahenkorah, Y. & Akrofi, G. S. (1969) Recent results on fertilizer experiments on shaded cocoa (*Theobroma cacao* L.) in Ghana. *Proc. 3rd Int. Cocoa Res. Conf.* pp. 23-29. Accra, Ghana.

Ahenkorah, Y., Akrofi, G. S. & Adri, A. K. (1974) The end of the first cocoa shade and manurial experiment at the Cocoa Research Institute of Ghana. *J. hort Sci.* **49**, 43-51.

Ahenkorah, Y., Halm, B. J., Appiah, M. R. & Akrofi, G. S. (1981) Fertilizer use on cocoa rehabilitation projects in Ghana. *8th Int. Cocoa Res. Conf. Cartegena, Colombia.* pp. 165-170.

Ahenkorah, Y., Halm, B. J., Appiah, M. R., Akrofi, G. S. & Yirenkyi, J. E. K. (1987) Twenty years results from a shade and fertilizer trial on Amazon cocoa (*Theobroma cacao* L.) in Ghana. *Expl Agric.* **23**, 31-39.

Ahenkorah, Y. & Appiah, M. R. (1996) Promoting food security through soil fertility management in food and non-food crops. *Proceedings of the National Workshop on Soil Fertility Action Plan for Ghana* (ed. F. Ofori and E. Y. Safo), pp. 61-75. Cape Coast, University of Cape Coast.

Appiah, M. R., Sackey, S. T., Ofori-Frimpong, K. & Afrifa, A. A. (1997) The consequences of cocoa production on soil fertility in Ghana - A review. *Ghana Jnl agric. Sci.* **30**, 183-190.

Campbell, C. A. M. (1984) The influence of overhead shade and fertilizers on the Homoptera of mature upper-Amazon cocoa trees in Ghana. *Bull. entomol. Res.* **74**, 163-174.

Charter, C. F. (1953) *Cocoa soils, good and bad.* Cyclostyled, WACRI Report.

Cunningham, R. K. & Arnold, P. W. (1962) The shade and fertilizer requirements of cocoa (*Theobroma cacao* L.) in Ghana. *J. Sci. Fd Agric.* **13**, 213-221.

Cunningham, R. K. & Smith, R. W. (1961) The significance of some recent work in Ghana on shade and nutrient requirements of cocoa. *Rep. Proc. Cocoa Conf., 1961* (Lond.), pp. 119-122.

Lodos, N. (1967) Studies on *Bathycoelia thalassina* (H.S.) Hemiptera, Pentatomidae), the cause of premature ripening of cocoa pods in Ghana. *Bull. ent. Res.* **75**, 289-299.

Omotoso, T. I. (1975)Technical and research aspects of soil fertility and fertilizer use in Nigeria with special reference to cocoa. *Phosphorus in agriculture* **1975** (29), 37-42.

Quartey Papafio, E. & Edwards, D. F. (1961) The use of fertilizers on cocoa in Ghana. *Rep. Proc. Cocoa Conf. 1961* (Lond.), pp. 123-125.

Smith, R.W. & Acquaye, D. F. (1963) Fertilizer responses on peasant cocoa farms in Ghana: A factorial experiment. *Emp. J. expl Agric.* **31**, 115-123.

Urquhart, D. H. (ed.) (1955) *Cocoa.* London, Longmans, Green and Co. 34 pp.