GENETIC IMPROVEMENT AND COCOA YIELDS IN GHANA

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Revised December 2003 – as submitted to *Experimental Agriculture*

SUMMARY

This paper estimates the yield gains attributable to the breeding of new cocoa varieties in Ghana. Genetic improvement is slower and more difficult for tree crops than for annuals, but significant progress has been made. We use data from a survey in mid-2002 of 192 farms from the country's key cocoa producing regions, and find that the use of the most recently-released varieties is associated with at least 51 percent higher yields. The use of fertilizer is associated with 21 percent higher yields. We find no evidence that newer varieties suffer from more rapid yield declines over time, or that they differ from older varieties in their response to fertilizer.

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Thanks are due to numerous colleagues and the surveyed farmers in Ghana for their invaluable assistance, as well to Rob Lockwood for pointing us to archival materials on the history of cocoa breeding, and to the Africa Bureau of USAID for funding through USDA cooperative agreement no. 58-3148-6-082.

INTRODUCTION

Agricultural research has led to substantial productivity increases and poverty alleviation around the world (Evenson and Gollin, 2003). Numerous case studies show similar effects in Africa (Masters, Oehmke and Bedingar, 1998). These gains have been greatest for annual crops, partly because genetic improvement can occur more quickly when reproduction occurs faster. Slow maturation not only delays the breeding process for a perennial crop such as cocoa but also the payoff to farmers, due to the slow growth of the tree itself, making it more difficult for them to finance the private investment needed for adoption. As a result, there tends to be less genetic improvement in perennials than in annual crops, and what little breeding is done is more likely to occur in the public sector than the private one.

The cacao crop has a long history in Ghana. In 1878, a trader named Tetteh Quarshie returned home from Fernando Póo (now Bioko in Equatorial Guinea) bringing with him cacao seeds of the highly uniform West African Amelonado variety which were planted in the Akwapim mountains of the of the Eastern Region of the Gold Coast (now Ghana). Nearly a decade later, Governor Griffiths, then Governor of Ghana, effectively repeated Tetteh Quarshie's introductions (Lockwood and Gyamfi, 1979), the trees being planted at the Botanic Gardens at Aburi. There were further introductions to Aburi between 1900 and 1909 of Trinitarios from Jamaica, Trinidad and Venezuela. The new industry grew rapidly across the country, and in 1910 Ghana became the world's leading cocoa producer accounting for 30-40 percent of the global market (Bateman, 1990). In the mid-forties it was estimated that over 90% of the trees in Ghana were of Amelonado type, the remainder being descendants of the Trinitario introductions. Production levels peaked in 1964, then declined for twenty years. Recovery began in 1984, reversing almost all of the decline (Food and Agriculture Organisation, 2002).

Traditionally, Ghana's cacao was grown with minimum purchased inputs (for example, Beckett, 1945), although it has long been recognized that soil nutrient reserves would become exhausted eventually (Charter, 1953). Recently, Appiah, Sackey, Ofori-Frimpong and Afrifa (1997) argued that soil nutrient availability has indeed become limiting to cacao yields. Appiah, Ofori-Frimpong, Afrifa and Asante (1997) reported a doubling of yields in Ghana from the application of 4.94 bags of triple super phosphate and 2.47 bags of muriate of potash per ha^{-1} over a four year period.

The recovery of Ghana's cacao industry after 1984 coincided with dramatic economic reforms, such as exchange rate devaluation that stimulated the production of all exports. But it also involved sector-specific efforts to revive the cacao industry, such as the multiplication and distribution of new varieties (Abdulai and Reider 1996). This paper outlines the development and impact of these varieties, recognizing that the economic reforms and other factors helped make their adoption profitable.

MATERIALS AND METHODS

Cacao varieties in Ghana

The origin of the cocoa planting material made available in Ghana from time to time is summarized in Table 1. The seedling varieties that are planted today originate in

[Insert Table 1 near here]

cross-breeding efforts that began in the 1940s. When the Central Cocoa Research Station (later West African Cocoa Research Institute W.A.C.R.I. and then Cocoa Research

Institute of Ghana (CRIG)) was established in 1938, it had been agreed that planting material should be distributed as seed and not as clones (Posnette, 1943). A collection of clones was made from experimental farms and farmers' cacao (Posnette, 1943). In trials, the selfed progenies of these clones did not out-perform the parent plant. Thus using the seedling progeny of 28 West African Amelonado clones and 2 clones of doubtful antecedents (Posnette, 1951), the first progeny trials of high yielding cacao selections were planted between 1940 and 1943. Two non-Amelonado progenies, E1 and N38, gave the highest number of bearing trees, the most pods and the highest weight of beans per pod. The second progeny trial, which took place up to 1950, was designed to compare the yield of the progenies of 1 Amelonado and 35 Trinitario clones. The results confirmed the early bearing habit and relatively high yield of the E1 progeny in the first progeny trial, and indicated that certain Trinitario clones, notably TF1, may have even higher yielding progeny. Detailed results of these and subsequent trials can be found in Posnette (1951); Knight and Rogers (1955); Glendinning and Edwards (1962); Glendinning (1963) and Lockwood (1976).

It became apparent that the locally available germplasm would not permit a successful breeding programme for resistance to mirids (*Distantiella theobromae* and *Sahlbergella singularis*) and swollen shoot virus disease (Posnette, 1951). In 1944, a solution to this problem was sought in the transfer of seedling germplasm from Trinidad, including material from Brazil, Costa Rica, Ecuador, Nicaragua, Peru, Surinam, Trinidad and Venezuela.

The Upper Amazon collections from Peru, showed superior vigour and precocity when compared with the Lower Amazon, Criollo, Ecuador, Trinitario, and West African Amelonado types (Posnette, 1951). The need to replace trees that had been cut out in the campaign to contain the spread of swollen-shoot virus prompted the rapid multiplication of the Upper Amazon material. Its precocity was seen to be especially advantageous (Knight and Rogers, 1955) in enabling affected farmers to get back into production quickly. "Gentleman's Agreement" plots of mixed second generation open-pollinated Upper Amazon material were established from 1950 onwards, to test the material under farmers' management. In 1954, ten of the Upper Amazon types were approved for distribution to farmers as third generation open-pollinated seed (Hammond, 1955). An eleventh type was added in 1957 (Hammond, 1958). This became known as the "F_3 Amazon" or "Mixed Amazon" material. By March 1961 sufficient pods and seeds had been distributed to plant an estimated 60,000ha (Glendinning and Edwards, 1962).

While the Mixed Amazons were being multiplied, Knight and Rogers made exploratory crosses between Upper Amazon seedlings selected within the Trinidad introduction and some of Posnette's (1943) local Trinitario selections or their self-pollinated descendants. Trials of seven and six potential new varieties (including reciprocal crosses) were established in 1952 and 1954 respectively. They became known as the "Series II Hybrids[2]". In 1955, seven of them were selected for evaluation at more sites, with a single inter-Upper Amazon cross included at all of them. In 1960, bi-clonal seed gardens were established to mass produce seeds of six of Series II hybrids, relying

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[2] Strictly these and other "hybrid" cacao varieties are bi-parental crosses as the parents are not inbred

on self-incompatibility and natural pollination. There were five Upper Amazon, three Amelonado and three Trinitario parents.

The accumulated results from all the Series II trials were re-assessed in 1970. It was concluded that as group, the Upper Amazon x Amelonado hybrids were preferable to the Trinitario ones, yielding about 11% more and showing markedly lower losses from black pod disease (caused by infection with *Phytophthora palmivora*). The best Amelonado hybrid yielded 15% more than the average of the Trinitario hybrids, with lower losses from black pod disease; a difference that was expected to be amplified under smallholder management. The one inter-Amazon hybrid was comparable to the Amelonado ones in field performance (Anon, 1970). In a single comparison, the Amelonado hybrids out-yielded Amelonado by about 45%, compared to 14% for the Trinitario hybrids (Lockwood, 1976). In Ghana, there was no formal comparison between the Series II hybrids and Mixed Amazons.

In 1969 seed garden output was low, because the Upper Amazon clones had proved to be easier to establish, more vigourous and more floriferous than the Amelonados and Trinitarios. A manual pollination technique was developed that allowed large scale production of high quality seed from the Upper Amazon parents, at low cost, and with a measure of control over seasonal periodicity of production (Edwards, 1973). This allowed substitution of Amelonado for the local Trinitario in all the seed gardens planted with one of the four self-incompatible Upper Amazon clones (the fifth was self-compatible, and was abandoned). Seed production averaged 1.65m pods pa from 1973/74 to 1991/92, with a range of 1.16 to 2.05m (E.G. Asante, personal communication 2003). Over the last ten years, the average was 1.5 million rising to 1.99m in 1997 and

3m in 2001. Assuming 125 pods are required to plant one ha^{-1} of cocoa (allowing considerable wastage), 1.5m pods is enough for $12,000ha^{-1}$ pa.

When the change was made to using Amelonado as the pollen parent, it was known that some Upper Amazon clones confer on their progeny a useful measure of resistance to the spread of swollen-shoot virus (Posnette and Todd, 1951; Legg and Kenten, 1971). Trials were planted by the British Research Team (BRT) to evaluate Upper Amazon clones as alternative pollen parents for the four self-incompatible Upper Amazon parents (Lockwood, 1981). The objective was to combine the ease of establishment and precocity of the Series II hybrids with greater resistance to the spread of virus. In 1985, the results of these trials were used to choose four Upper Amazon pollen parents for each of the seed gardens. On average, these crosses were slightly higher yielding and showed lower blackpod losses than the Amelonado crosses they replaced (Enuson and Adomako Boamah, 1985). These crosses are referred to here as the BRT hybrids. A recent evaluation of 23 farm plantings with this type of material showed that virus spread had been relatively slow over a 25-year period (Ollennu and Owusu, 2002), confirming the results of Legg and Lockwood's (1981) field experiments.

Several of the Series II hybrids and the later BRT hybrids were planted in large scale agronomy experiments. The results from those trials indicated that breeders' trials tended to under-estimate the difference between bi-parental crosses. In one experiment the best of the Series II Amelonado crosses outyielded a Series II Trinitario cross by 53% based on the number of useable pods (Ampofo, Frimpong, Addo and Dakwa, 1986). The difference in yield of dry beans would have been smaller given that the Amelonado cross has smaller pods. In another trial, three of the BRT hybrids had potential yields 28%

higher than a Series II Amelonado cross (Appiah, Ofori-Frimpong and Afrifa, 2001). Enuson and Adomako Boamah's blackpod data suggest the difference in actual yields would have been larger. In a third trial, three of the BRT hybrids outyielded the best of the Series II Amelonado crosses by 36% (Osei-Bonsu, Acheampong, Amoah, Oppong and Opuku-Ameyaw, 2002).

The survey

Information for this paper comes from both primary and secondary sources. The primary source is a field survey undertaken in mid-2002 in the Ashanti and Western Regions, Ghana's principal cacao growing areas. A total of 123 randomly selected farmers from 20 villages were sampled and visited by this paper's first author, accompanied by a local translator. The number of fields owned by each farm varied between 1 and 3 resulting in a total of 192 fields being analyzed in this study after data cleaning and collation. Secondary data on the breeding programme of cacao in Ghana was obtained through research reports, journal articles and personal communication with individuals involved in the cacao sector and its genetic improvement.

The field survey was conducted directly with farmers, not necessarily land owners or heads of household, to increase the accuracy of the responses. The survey asked these farmers to describe the types of cacao being grown, sources of seed pods, their dates of planting and the age of the farm(s), and also asked about a range of other factors that might influence cocoa yields. Some data were also collected on the other crops being grown.

In order to verify the varieties grown by farmers, the lead researcher initially visited CRIG to learn from researchers the types of varieties released to farmers and their identification at field level. In addition, during the field survey, experienced extension agents in the region and cocoa buying clerks accompanied the lead researcher for data collection and in particular verifying the type of varieties cultivated by the farmers. The survey team also relied on memory recall of farmers for the dates of planting their plots and inputs used. Yields reported by farmers were also recorded and cross-checked with their sales record books and the records of the cocoa buying companies.

Description of the data and analysis

Descriptive statistics of the data collected are presented in Table 2. In

[Insert Table 2 near here]

addition to the average of 3.5 ha^{-1} in cacao listed in Table 2, farm households planted a mixture of food crops (cassava, plantain, yam, and maize) for home consumption, on an average land area of 0.8 ha^{-1}. The input use levels reported on the table are far below agronomic recommendations, which is typical for low-income farmers who have little savings or credit available to them at the start of the growing season.

To determine the influence of variety on the productivity of cacao, we classify farms by the variety used. Typically, whole farms are planted to new stock simultaneously, in a single variety. Replanting the same farm with a mixture of varieties was uncommon, but new planting through area expansion was practiced.

In addition to describing the current situation, our goal was to test the magnitude of correlation between dry cocoa yield and hybrid variety use, controlling for other factors. We used two stage least squares (2SLS) method to estimate the following equation:

$$ln(yield_i) = \alpha_0 + \beta_1 \hat{h}_i + \mu_i x_i + \varepsilon_i \quad (1)$$

$ln(yield_i)$ is the natural logarithm of the yield of cocoa per acre and $\hat{h}$ is the predicted cultivation of hybrid from the first stage regression. X_i denotes additional observed control variables, α_0 and μ_i are unknown parameter, ε_i is the error term. If that error term were correlated with hybrid adoption, perhaps because some unobserved third factor were influencing both adoption and yields, the ordinary least squares estimate of β_1 would be subject to endogeneity bias. To obtain a consistent estimate of β_1, we therefore replace observed adoption with its predicted values from a separate first-stage regression that takes account of other exogenous factors.

The coefficient of interest is β_1, which is a representation of the percentage change in each farmer's yield ($yield_i$) associated with that farmer's use of hybrid variety (h_i). The coefficient μ_i includes all other variables that might intervene to affect the yield of finished cocoa beans.

In this study we have categorized varieties released into two groups. Following local usage, we categorized all pre-1980 varieties as "traditional", and refer to all later releases as "new". The spread of the post-1980 new varieties was heavily influenced by government policy. Prior to 1984, economic policy penalized the production of cocoa or other exports, leading farmers to neglect standing trees and not plant new ones. Furthermore, in early 1980, Ghana experienced a devastating bushfire and drought in the south and also infestation by cocoa swollen shoot virus (CSSV) in the East that led to government-enforced cutting of cacao trees, particularly the older ones (Ministry of Finance, 1999). In 1984, with World Bank support, the government launched its Cocoa Rehabilitation Project (CRP). The CRP included distribution of improved cocoa varieties to farmers, especially in the Western region (Bloomfield and Lass, 1992)

RESULTS AND DISCUSSION

The impact of new varieties

The results for our estimated yield function are shown in Table 3. The first model

[Insert Table 3 near here]

specification shows direct influences only, the second tests for interaction effects between variety adoption and input use, and the third tests for non-linear effects of tree age. Results show clearly that hybrid adoption is closely correlated with yield, increasing yield by at least 51 percent, and cocoa yield increases with fertilizer use. Interaction effects between variety adoption and input use are not significant, indicating that the productivity of new varieties is not conditional on input use, but tree age is clearly significant particularly when entered as age squared, indicating that yields decline mainly at high levels of age.

The impact of cacao breeding on farmers' yields is apparent not only from the statistical results of Table 3, but also from visual inspection of Figure 1, which shows

[Insert Figure 1 near here]

yield by age of planting for farms planted with new varieties and with traditional varieties. The partial correlation shown in the Figure might not represent causality, to the extent that other factors intervene to influence yield, for example fertilizer use as is discussed below. The new varieties first appear in our sample on a farm that was planted in 1985, and so was 17 years of age at the time of the survey. That farm now yields approximately twice as much cocoa/ha^{-1} as the similar-aged farms that were planted with traditional varieties. This yield advantage holds for subsequent plantings as well. After 1985, our sample is increasingly dominated by the new varieties, and the traditional varieties disappear entirely from the farms planted after 1995. Although yields vary over the lifespan of the tree, rising as it matures, then stabilizing and eventually falling, there is no evidence that the new varieties are more vulnerable to yield decline over the 17-year horizon for which we have data.

This study is believed to be the first field verification of the yields of improved cacao varieties when planted by farmers in Ghana. The gain in yield is larger than would have been predicted from the results of the breeders' trials, but is consistent with the results of larger scale agronomy trials. This result is important to the breeding programme because conditions in trials necessarily differ from those on farms and it appears that any genotype x environment interaction due to differences in husbandry practice has no practical consequences for selection.

The effect of fertilizer use

Figure 2 shows the association between yield and fertilizer use. Although most

[Insert Figure 2 near here]

farmers applied no fertilizer in 2002 and some of their yields were relatively high, increasing fertilizer use is clearly associated with higher yield.

This result was further strengthened by the regression estimates. The coefficient on fertilizer is positive and significant, contributing 21 percent increase in yield when controlling for all other variables. The result is consistent with on-station experimental results that the use of inorganic fertilizer will increase the yields of cocoa and that greater yield is obtained when hybrid varieties are cultivated with fertilizer than without. However with input subsidy withdrawal resulting from market liberalization, fertilizer prices have increased, reflecting its full market cost. Farmer utilization of fertilizer for cocoa production has thus dropped significantly.

At current prices our survey helps explain why farmers are not very keen on the application of fertilizer. Though the marginal value product (MVP)[3] of fertilizer for both categories of varieties (244,596 cedis for the new varieties and 128,605 cedis for traditional varieties), controlling for all other variables in the preferred model in table 3, is far above the average price of fertilizer paid by farmers (60000 cedis for 50 kg bag) therefore deserving the recommendation of fertilizer use, farmers have the concern that fertilizer effect is not large enough to outweigh its cost and realize adequate profits. This concern is investigated here using partial budget analysis as summarized in table 4, extending the work of Jones (1991), using survey data instead of Jones' series of on-station, multi-locational and on-farm trials. All prices are based on the actual amounts paid for inputs and received for farm output by farmers during the production period. The Table reports production of both new and traditional cocoa varieties under different

[3] The marginal value product of fertilizer (f) was computed from the regression estimates as the product of the first derivative of model 1 in table 3.5 at the average cocoa yield level of the variety(v) and the price(p) of the variety i.e. MVP = $\{\exp(b_f) - 1\} * P_v *$ average yield of variety.

[Insert Table 4 near here]

regimes of fertilizer use. The result indicates that though the application of fertilizer shows higher returns, irrespective of variety, than at zero fertilizer use, the returns at current farmer management level is however low. This result validates farmers' disinclination to cultivate cocoa with fertilizer especially when the cocoa plantings are in their full bearing stage and returns are high even at no fertilizer use. The returns to CRIG's recommendation are quite high especially the case of the new varieties. However, noting the high price of fertilizer, the small scale of operation of these farmers and assuming that farmers may have to borrow to purchase fertilizer, may inhibit the adoption of CRIG fertilizer recommendation.

Another reason for farmers' disinclination to fertilizer use is that farmers have become accustomed to growing cocoa with minimum fertilizer (Beckett, 1945) or no fertilizer application especially when the crop is mature and soil fertility becomes limiting (Charter 1953; Appiah, Sackey, Ofori-Frimpong and Afrifa, 1997), at which stage it takes about four years for the full fertilizer effect to be seen on cocoa output (Appiah, Ofori-Frimpong, Afrifa and Asante 1997).

CONCLUSION

In summary, our results demonstrate that the multiplication and distribution of new cacao varieties developed in Ghana has raised farmers' yields by at least 51 percent, controlling for other factors. The results clearly demonstrate that the multiplication and distribution of new varieties is of great importance for the productivity of cocoa and for the growth of

Ghana cocoa industry. Generally, the benefit of research does not only accrue to the farmers but to other parts of the Ghana economy plus a global spillover resulting from commodity export. The Ghana government should therefore invest in the production, multiplication and distribution of new varieties to farmers. These varieties are the outcome of almost fifty years of research effort, illustrating the benefit of continuity of investment and management. These efforts should be strengthened through continued support to research and seed distribution. One way is to encourage private sector interest in public agricultural research. Collaborations with the private sector will serve to supplement limited public R&D resources.

The other factors that matter most are fertilizer use, particularly in conjunction with pesticide use.

Market and price policies have also been very important for the cocoa sector, but technical innovation plays a separate and distinct role in raising farmers' and national income. This effect is difficult to observe in cacao due to the crop's slow maturation and long life, but our results clearly demonstrate that the multiplication and distribution of improved seedlings is of great importance for the productivity of the cocoa sector.

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Table 1. Stages in cocoa varietal development programme in Ghana

Collections/Introductions	Source	Period of release	*Years to bearing
"Traditional Varieties"			
Amelonado	Equatorial Guinea	before 1887	6-8
Trinitario	Trinidad, Jamaica, and Venezuela	1900-1909	6-8
Mixed Amazon	Peru via Trinidad	1950s	5-6
Upper Amazon x Amelonado and local Trinitario (originally series II Hybrids)	Peru and WACRI	1966-1970	4-6
Upper Amazon x Amelonado hybrids (Modified Series II hybrids)	WACRI	1971-1985	2-3
"New varieties"			
Inter-Amazon (BRT collection)	British Research Team (BRT)	Mid-1980s	2-3
Mutant hybrids (MV5)	Current CRIG collections	1990s	4

Source: Author interviews with CRIG staff, 2002, personal discussion with Rob Lockwood (2003) and review of literature.
*Years to bearing is sensitive to soil fertility and husbandry practices, especially shade management.

Table 2. Descriptive statistics for key variables (n=192)

Variable	(units of measure)	Mean	Standard deviation	Min	Max
Output	(kg/ha^{-1})	294.80	122.69	71.20	754.60
Output (Traditional)	(kg/ha^{-1})	258.83	82.69	101.04	552.02
Output (hybrid)	(kg/ha^{-1})	497.00	107.84	328.68	933.62
Farm area	(ha)	3.50	3.13	0.40	17.00
Age of plantings	(years)	20.13	12.79	3.00	56.00
Fertilizer use	(50 kg bags/ha^{-1})	0.53	1.25	0.00	6.50
Pesticide use	(litres/ha^{-1})†	1.87	2.88	0.00	22.00
Hired labour use	(man-days/ha^{-1})	10.93	6.82	0.00	125.70
Family labour use	(man-days/ha^{-1})	23.43	7.50	1.87	170.24
Family size	(persons)	10.69	4.85	1.00	25.00
Dependents	(persons) ‡	5.05	2.63	0.00	11.00
Age of farmer	(years)	46.34	15.47	20.00	77.00
Credit	(1=has access, 0 otherwise)	0.45	0.50	0.00	1.00
Education of farmer	(1=literate, 0 otherwise)	0.50	0.50	0.00	1.00

Source: Authors' survey data, 2002.
† The pesticide used by surveyed farmers is Gammalin, a trade name for Lindane.
‡ Defined as those dependent on farmer for livelihood, without contributing to the farm.
n = sample size

Table 3. Yield function coefficients estimated using two stage least squares probit

Dependent variable: *ln(yield)* (n=192)	Model (a) preferred specification		Model (b) interaction effects		Model (c) nonlinear age	
	Estimated coefficient	*s.e.*	Estimated coefficient	*s.e.*	Estimated coefficient	*s.e.*
Independent variables						
Intercept	4.81	0.053	4.70	0.06	4.46	0.080
Hybrid adoption	0.42*	0.045	0.56*	0.06	0.59*	0.055
Fertilizer use	0.19*	0.035	0.12	0.16	0.19	0.156
Pesticide use	-0.00	0.014	0.08	0.04	0.07	0.037
Hired labour use	-0.00	0.002	-0.00	0.00	-0.00	0.002
Age of planting	-0.01*	0.002	-0.01*	0.00	0.01	0.006
$(\text{Age of plant.})^2$					-0.00*	0.000
Interaction effects						
Hybrid x fertilizer			-0.02	0.17	-0.08	0.164
Hybrid x pesticide			-0.09	0.04	-0.07	0.040
Hybrid x labour			-0.00	0.00	-0.00	0.004
Fertilizer x pesticide			0.41	0.26	0.31	0.253
Hybrid x fertilizer x pesticide			-0.35	0.28	-0.23	0.264
r^2	0.695		0.725		0.750	

*$p < 0.001$.
n = sample size (192 for each model)
$r^2 =$ amount of total variation in the dependent variable that is explained by the independent variables.

Table: 4. Per acre profitability of fertilizer use in cocoa production[1]

	Production with zero fertilizer (n =98)		Production with average fertilizer use[2] (n=19)		Production with CRIG recommended rate[3] (n=6)	
Variety	Traditional	Hybrid	Traditional	Hybrid	Traditional	Hybrid
Yield (kg ha^{-1})	227.85	480.20	286.65	651.70	396.90	735.00
	Values in '000 cedis					
Value[4]	883	1860	1,110	2,145	1,537	2,847
Total Operating Cost	272	281	469	575	864	958
Returns	611	1,579	641	1,570	673	1,889
Benefit/Cost ratio	2.24	5.62	1.36	2.73	0.77	1.97
Difference associated with new varieties		968		925		1,216
Difference associated with Fertilizer use			30	-9	62	310
Difference associated with Fertilizer use at minor crop price[5]			168	769	456	903

[1] Results based on survey data, 2002

[2] The average fertilizer use was one bag per acre

[3] CRIG recommendations is one bag of triple superphosphate mixed with a bag of sulphate of potash or 0.75 bag of muriate of potash

[4] Producer price during the earlier part of the production period (Sept- Dec, 2001) was 3874 cedis kg^{-1}.

[5] Producer price changed to 6200 cedis kg^{-1} during the season (Feb- May, 2002)

Currency exchange rate: 1 US $ = 7000Cedis

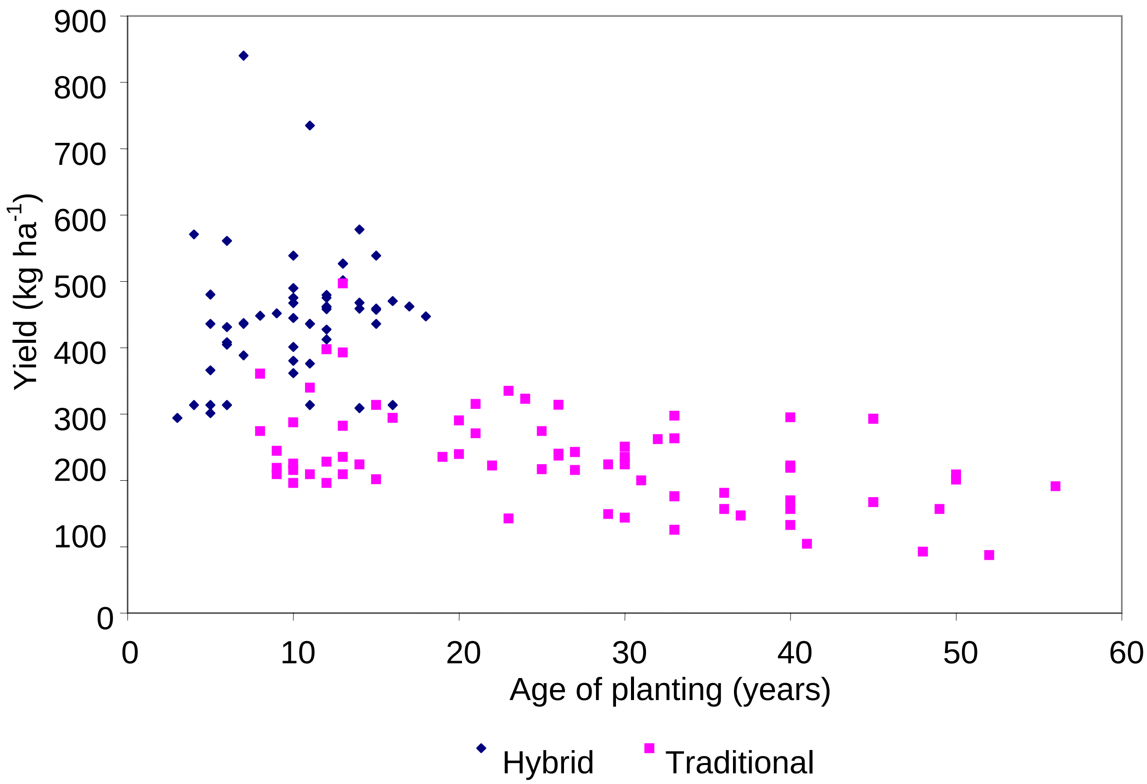

Figure 1: The effect of age of plantings on the yield of cocoa

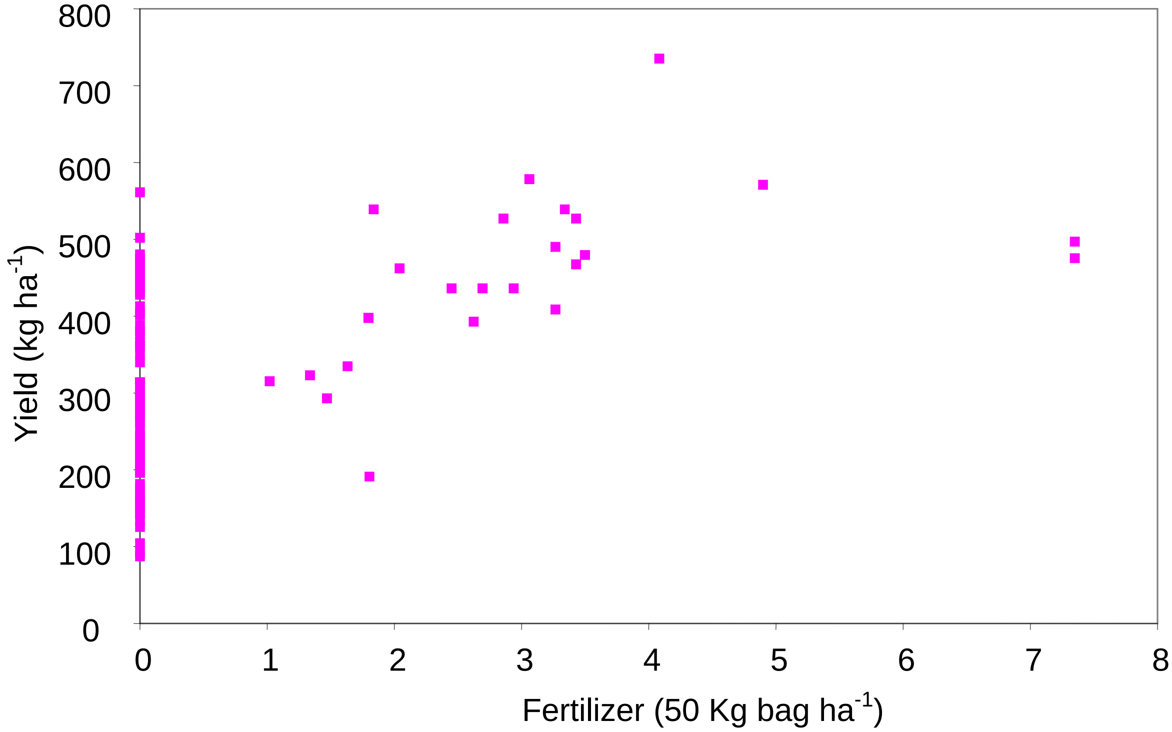

Figure 2: The effect of fertilizer on the yield of cocoa