

# Growth and nutrient uptake of some cocoa varieties grown in contrasting soils

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## ABSTRACT

A comparative growth analysis and N, P and K contents of six cocoa varieties grown in two cocoa-growing soils of different fertility status under greenhouse conditions were carried out over a period of 12 months. The cocoa varieties studied were inter amazon crosses, namely: T85/799 × Amel, T79/501 × T85/799, T85/799 × Pa7/808, APA 5 × Pa7/808, T60/887 × Pd 15, and T79/501 × ALPHA B 36. The experiment was a factorial in randomised block designed with three replicates. Seedling height, stem girth, root length, and total dry weight were recorded at 3-month intervals. N, P and K concentrations of the roots and shoots of the seedlings were determined. Seedling growth was better in the relatively fertile soil than in the relatively poor soil. The differences in growth rates among the varieties in both soils were not significant. T85/799 × Pa7/808 and T79/501 × ALPHA B 36 grew more vigorously and produced higher dry matter yields, whilst T79/501 × T85/799 showed slower growth rates in both soils. Cocoa varieties grown in the relatively poorer soil had significantly longer roots than those grown in the relatively fertile soil, with T60/887 × Pd 15 recording the longest root length in both soils. The differences in NPK uptake among the varieties in each soil were not significant. However, the absolute amounts of the nutrients in the plant tissues tended to be highest in T85/799 × Pa7/808 and T79/501 × ALPHA B 36 for both soils. The uptake of the nutrients by the cocoa varieties was in the order N>K>P. Although P was the least absorbed by the varieties, P concentrations in the plant tissues related positively with the dry matter yield of the varieties. Selection of cocoa varieties with higher root to shoot ratios and shorter root lengths for planting in suitable and marginal soils as well as top dressing of seedlings with P fertilizer may be recommended in the cocoa rehabilitation programmes in Ghana.

## RÉSUMÉ

OFORI-FRIMPONG, K., AFRIFA, A. A. & APPIAH, M. R.: *Croissance et absorption de substance nutritive de quelques variétés de cacao cultivées dans les sols contrastés.* Analyses de croissance comparative et les contenus de N, P et K de six variétés de cacao cultivées en deux sols de différent statut de fertilité de la production de cacao sous les conditions de la serre se déroulaient sur une période de 12 mois. Les variétés de cacao étudiés étaient les hybrides interamazons, à savoir T85/799 × Amel, T79/501 × T85/799, T85/799 × Pa 7/808, APA 5 × Pa 7/808, T60/887 × Pd 15 et 79/501 × ALPHA B 36. L'expérience était factorielle dans un bloc choisi au hasard dessiné avec trois réplicatifs. Taille de semis, circonférence de tige, longueur de racine et poids total du produit sec étaient enregistrés à trois intervalles mensuels. Les concentrations de N, P et K des racines et des pousses des semis étaient déterminées. La croissance de semis était meilleure dans les sols relativement fertiles que dans les sols relativement infertiles. Il n'y avait aucune différence considérable en proportion de croissance parmi les variétés dans les deux sols. T85/799 × Pa 7/808 et T79/501 × ALPHA B 36 poussaient plus vigoureusement et produisaient des rendements de matière sèche plus élevés, alors que T79/501 × T85/799 montraient des proportions de croissance plus lentes dans les deux sols. Les variétés de cacao cultivées dans les sols relativement infertiles donnaient considérablement des racines plus longues que celles dans les sols relativement fertiles avec T60/887 × Pd 15 enregistrant la plus grande de longueur de racine dans les deux sols. Les différences en absorption de NPK parmi les variétés dans chaque sol n'étaient pas considérables. Cependant, les quantités absolues des substances nutritives dans les tissus de plante avaient tendance d'être plus élevées en T85/799 × Pa 7/808 et T79/501 × ALPHA B 36 pour les deux sols. L'absorption d'élément nutritif par les variétés de cacao était dans l'ordre N>K>P. Malgré que P était le moins absorbé par les variétés, les concentrations de P dans les tissus de plante avait une relation positive avec le rendement de matière sèche des variétés. La sélection des variétés de cacao avec des proportions de la racine contre la pousse et de longueurs de racine plus

Original scientific paper. Received 27 Mar 2001; revised 4 Oct 2002.

### Introduction

Cocoa cultivation in Ghana has in the past been based solely on exploiting the fertility built up by virgin forest. This has led to decline in soil fertility with consequential decrease in production (Appiah *et al.*, 1997). As a result of pressure on land for various activities, virgin forest for cocoa cultivation is no longer readily available. Soils which have been under intensive cultivation are now being used for cocoa cultivation. Attempts are being made to breed for vigorous and high-yielding cocoa varieties for planting. These varieties may have higher nutrient requirements, as Lockard & Asomaning (1966) and Omotoso (1975) reported higher concentrations of N, P and K in hybrid than in Amazon and Amelonado cocoa varieties.

In addition to the inherent genotypic properties of plants, Barber (1968) observed that growth of plants is also influenced by soil nutrients whose uptake is very much dependent on the supply and rate of absorption of the nutrients at the root surfaces. Baldwin (1975) also showed that an extensive root development is a pre-requisite to the successful exploitation of soil reserves of relatively immobile nutrients. In this context, for less mobile nutrients like P and K in a cocoa ecosystem, the amount of nutrient taken up by plants is a function of the length of the roots produced (Bray, 1954), since the roots must explore the soil thoroughly. Lockard & Asomaning (1966) related the higher amounts of nutrients in the more vigorous cocoa varieties to the many lateral feeding roots which enabled them to absorb more nutrients.

It seems, therefore, that the efficient use of native and added nutrients by cocoa would be influenced markedly by the extensiveness and the capacity of the root system to absorb contacted nutrients. However, these factors may differ

among the cocoa varieties. There is, therefore, the need to identify the varieties that are better extractors of particularly P and K, and are also well adapted to soils of low P and K contents because of the value of P and K nutrition in cocoa cultivation in Ghana (Ahenkorah *et al.*, 1981).

This study evaluates the significance of varietal differences in plant growth and N, P and K uptake efficiencies of some promising cocoa varieties grown in soils of different fertility status, with the ultimate aim of assisting in drawing up fertilizer recommendations for the cocoa varieties grown in Ghana.

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### Materials and methods

The experiment was conducted in a greenhouse at the Cocoa Research Institute of Ghana. It consisted of a factorial combination of two soil types, and six cocoa varieties of inter amazon crosses in a randomised complete block design with three replications.

Surface soil (0-15 cm) of the two soil types were collected from experimental farms of the Cocoa Research Institute of Ghana (CRIG) at two locations. On the first farm, the soil had carried cocoa for the past 33 years and had been grubbed, while on the second farm the soil had received a fertilizer mixture at the rate of 129 kg P<sub>2</sub>O<sub>5</sub> and 76.5 kg K<sub>2</sub>O per ha/year for 3 consecutive years. On this basis, the soil from the first farm was classified as relatively poor and that from the second as relatively fertile. Both soils are Ferric Lixisols (FAO/UNESCO, 1990). Table 1 shows some of their properties.

The cocoa varieties used were inter amazon crosses, namely: T85/799 × Amel, T79/501 × T85/799, T85/799 × Pa7/808, APA 5 × Pa7/808, T60/887 × Pd 15 and T79/501 × ALPHA B 36.

Polythene bags (35 cm × 25 cm) perforated at the base were filled with 5 kg of the surface soil

TABLE 1

*Some Physical and Chemical Properties of the Soils Used in the Experiment*

Soil	pH (H <sub>2</sub> O) (1:2.5)	Organic C (%)	Total N (%)	Available P (mg/kg)	Exchangeable cation			Sand	Silt	Clay
					K	Mg	Ca			
———— cmol(+)/kg ————										
Relatively poor	6.14	0.86	0.123	27.3	0.17	2.93	13.4	81.3	16.0	2.7
Relatively fertile	7.26	1.93	0.320	79.5	0.17	4.19	15.1	51.3	36.0	12.7

which had passed through a 2-mm sieve. Three seeds of each cocoa variety were planted in each bag. The seedlings that emerged were thinned to one per bag at 20 days after sowing. The bags were watered as and when necessary to keep the moisture content of the soil at field capacity. Sampling started 3 months after seedling emergence and continued at 3-month intervals for the next 12 months.

Growth measurements (height and girth) were taken on each sampling date. The polythene bag containing each of the sampled seedlings was torn apart and the whole seedling thoroughly washed with distilled water with the roots intact. The seedlings were partitioned into shoots and roots after which the fresh weights were taken. Root length was determined by the method of Tennant (1975). The relative growth rate (RGR) was calculated by the expression of Fisher (1921). The plant parts were dried to a constant weight at 80 °C for 48 h for the dry weights. Total N and P in the plant parts were determined by the methods of Bremner (1965) and Cavell (1995), respectively, while K was determined on an Atomic Absorption Spectrophotometer after acid digestion.

## Results and discussion

### *Growth parameters*

Table 2 shows data on plant height and girth increment of the cocoa seedlings in the two soils at 12 months after planting. In the relatively poor soil, the

differences in plant height and girth increments among the varieties were not significant, although T85/799 × Amel were taller while T85/799 × Pa7/808 had bigger girth than the other varieties. The lowest height and girth increments were recorded for T79/501 × T85/799 and T85/799 × Amel, respectively. In the relatively fertile soil, significant differences in plant height increments but not in girth increments were observed among the varieties, with T85/799 × Pa7/808 and T79/501 × ALPHA B 36 recording the tallest and biggest plants, respectively. APA 5 × Pa7/808, however, recorded the lowest height and girth increments. Plant growth generally tended to be better in the relatively fertile soil than in the relatively poor soils, except in APA 5 × Pa7/808 and T60/887 × Pd 15. This trend may be attributed to differences in the fertility status of the soils (Table 1). However, growth rates among the varieties for both soils were not significantly different, although T79/501

TABLE 2

*Growth Increments of Cocoa Seedlings at 12 Months After Planting*

Soil variety	Height increments (cm)		Girth increments (cm)	
	Poor soil	Fertile soil	Poor soil	Fertile soil
T85/799 × Amel	100.3	110.6 <sup>ab+</sup>	7.5	9.7
T79/501 × T85/799	72.3	99.0 <sup>a</sup>	8.6	8.5
T85/799 × Pa7/808	97.3	117.3 <sup>b</sup>	9.7	9.4
APA 5 × Pa7/808	87.5	61.2 <sup>c</sup>	9.2	6.3
T60/887 × Pd 15	77.2	75.0 <sup>cd</sup>	9.4	9.5
T79/501 × ALPHA B 36	74.8	82.0 <sup>d</sup>	9.4	11.2
Mean	84.9	90.0	8.9	9.1
P < 0.05	NS	*	NS	NS

+Figures followed by the same letter(s) in a column are not significantly different from each other.

× T85/799 showed slower growth rates in both soils (Table 3).

Table 4 shows data on total root length of cocoa seedlings at 12 months after planting. In both soils, the differences in root length among the varieties were not significant, although T60/887 × Pd 15 had the longest roots while APA 5 × Pa7/808 recorded the shortest roots in only the relatively fertile soil. Generally, cocoa grown in the relatively poor soil had significantly ( $P < 0.01$ ) longer roots than those grown in the relatively fertile soil. Powell (1974) observed that roots growing into soils that were low in available P had more and longer root hairs than roots growing into high phosphate soils. Similarly, Barber (1994) reported that when a plant is deficient in N or P, it apparently diverts relatively more photosynthate to the roots. Thus, the plant obtains greater root

length which in turn aids it to obtain more N or P. The longer roots of cocoa grown in the relatively poor soils may therefore be related to the low fertility status of the soil (Table 1). In the relatively poor soil, the roots possibly had to explore the soil more thoroughly for their nutrient supply.

#### *Dry matter production and distribution*

Dry matter yield of the cocoa seedlings generally increased with time (Fig. 1 and 2). In the relatively poor soil, the overall variation in the dry matter yield among the varieties at each stage of growth was not significant. However, at the final sampling, seedlings of T85/799 × Pa7/808 had the highest while those of T79/501 × T85/799 recorded the lowest total dry matter yield. In the relatively fertile soil, dry matter yields among the varieties were significantly different ( $P < 0.01$ ) at all stages

of plant growth. The highest dry matter yields were recorded for T85/799 × Pa7/808, while T79/501 × T85/799 recorded the lowest dry matter yield at the final sampling. The significant differences in the dry matter yield of varieties grown in the relatively fertile soil confirm the observation that edaphic factors influence the performance of varieties of similar genotypes (Kempton & Talbot, 1988).

At the final sampling in both soils, the shoot had the highest proportion of dry matter compared the roots. The proportion of dry matter in the roots of cocoa grown in the relatively poor soil ranged from 26 to 35 per cent, with T85/799 × Pa7/808 and T79/501 × ALPHA B 36 recording the highest percentages and T60/887 × Pd 15 the lowest. In the relatively fertile soil, the corresponding figures ranged from 16 to 22 per cent, with T85/

TABLE 3

*Some Growth Parameters of 12-month-old Cocoa Seedlings*

Soil variety	Relative growth rate (g/g/wk)		Root to shoot ratio (%)	
	Poor soil	Fertile soil	Poor soil	Fertile soil
T85/799 × Amel	0.0404	0.0470	30.3	16.9
T79/501 × T85/799	0.0385	0.0389	26.7	18.9
T85/699 × Pa7/808	0.0432	0.0440	33.6	22.1
APA 5 × Pa7/808	0.0398	0.0414	26.7	21.2
T60/887 × Pd 15	0.0411	0.0419	23.0	17.5
T79/501 × ALPHA B 36	0.0432	0.0463	35.8	22.9
Mean	0.410	0.0433	29.4	18.9
$P < 0.05$	NS	NS	NS	NS

TABLE 4

*Total Root Length of Cocoa Seedlings at 12 Months After Planting*

Soil variety	Relatively poor (m)	Relatively fertile (m)
T85/799 × Amel	2.93	1.05
T79/501 × T85/799	2.15	1.37
T85/799 × Pa7/808	1.78	1.13
APA 5 × Pa7/808	1.66	0.81
T60/887 × Pd 15	3.22	1.41
T79/501 × ALPHA B 36	1.50	1.26
Mean	2.21	1.17
$P < 0.05$	NS	NS

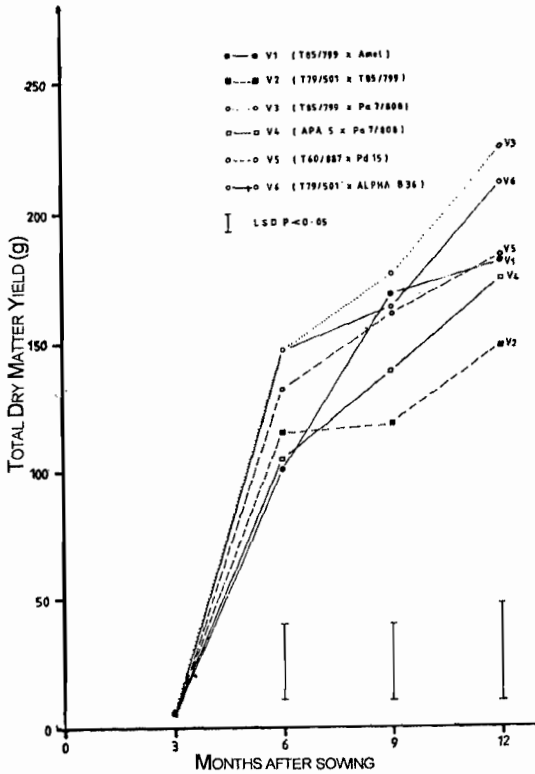


Fig. 1. Total dry weights of cocoa seedlings grown in relatively poor soil for 12 months after planting.

799 x Pa7/808 and APA 5 x Pa7/808 recording the highest percentages and T85/799 x Amel the lowest.

Table 3 shows the root to shoot ratios of the varieties in the two soils. The root to shoot ratios of cocoa grown in the relatively poor soil were significantly ( $P < 0.01$ ) higher than those grown in the relatively fertile soil. Barber (1979) observed that the total amount of roots can be influenced by the fertility level of the soil, and that the addition of nitrogen or phosphate can reduce the total yield or roots, even though shoot growth is increased. The highest root to shoot ratios for cocoa grown in the poor soil may therefore be due to diversion of more photosynthate to the roots for better growth in response to the lower content of nitrogen and phosphate in the soil

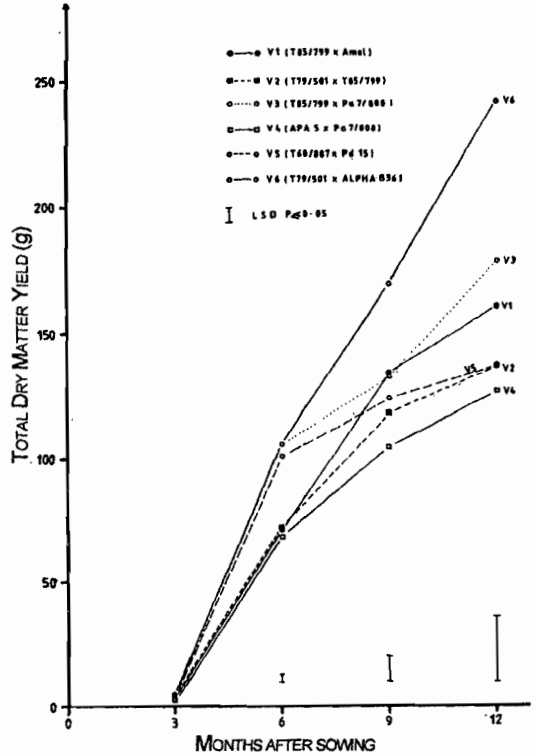


Fig. 2. Total dry weights of cocoa seedlings grown in relatively fertile soil for 12 months after planting.

(Barber, 1994).

*Nutrient uptake*

The relative nutrient concentrations in the cocoa seedlings at 12 months after planting are presented in Fig. 3 and 4. The nutrient concentrations were higher in the shoots than in the roots. In the relatively poor soil, the concentrations of N in the seedlings were similar, with T79/501 x ALPHA B 36 recording the highest N concentration compared to the other varieties. A similar trend was observed for P. Potassium concentration was highest in T85/799 x Pa7/808. In the relatively fertile soil, the concentrations of N and K were similar among the varieties, but P concentration was highest in T79/501 x ALPHA B 36. Although the relative concentrations of the nutrients were generally similar among the

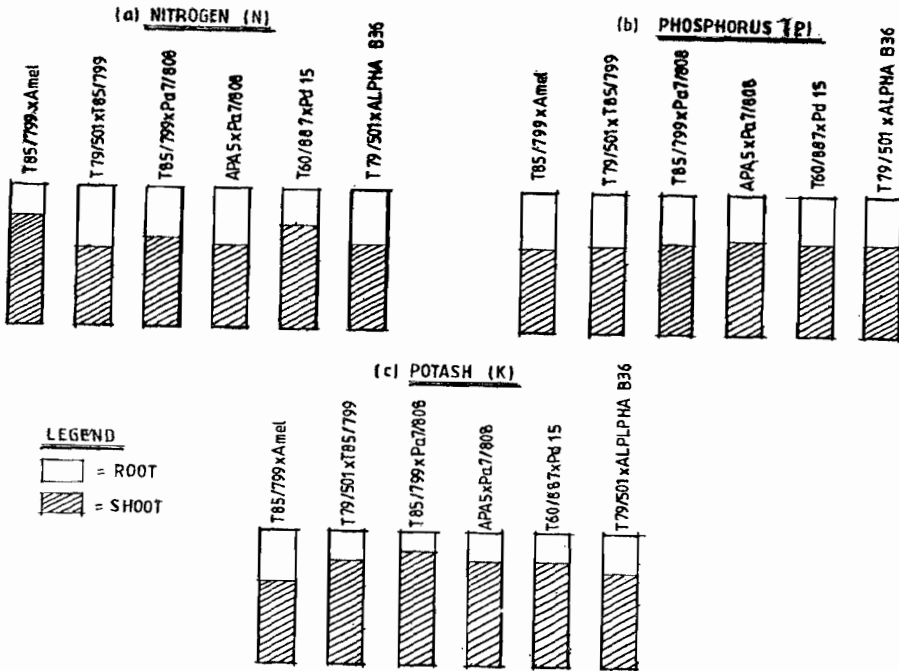


Fig. 3. Nutrient concentrations (%) in cocoa seedlings of 12 months old on relatively poor soil.

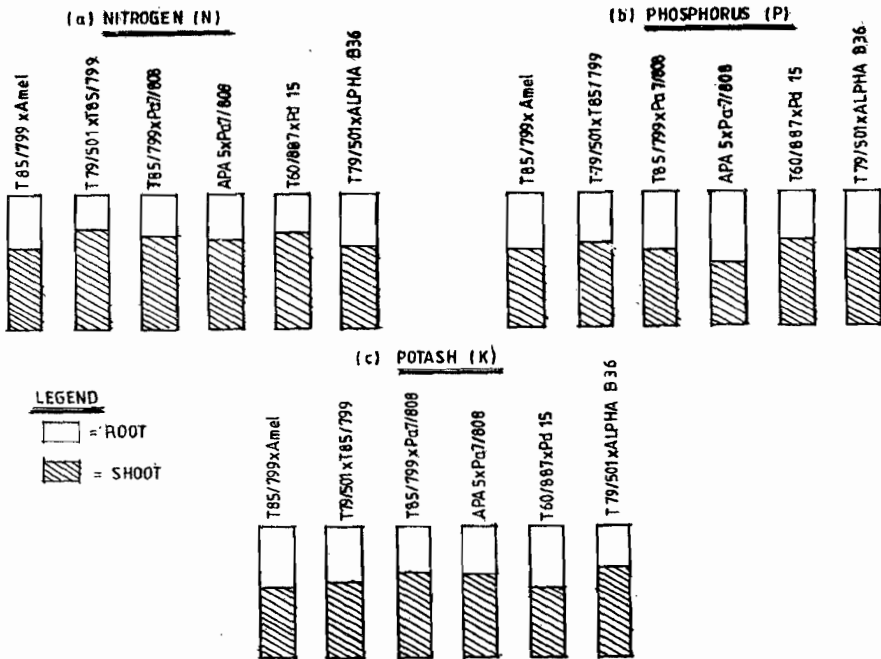


Fig. 4. Nutrient concentrations (%) in cocoa seedlings of 12 months old on relatively fertile soil.

varieties in the two soils, the absolute amounts of N, P and K, calculated as the product of the nutrient concentration and plant weight, were higher for T85/799 × Pa7/808 and T79/501 × ALPHA B 36 in both soils (Table 5). The uptake of K was significantly higher for seedlings of the relatively poor soil than for those of the relatively fertile soil. A possible reason for this trend may be the longer roots of the seedlings in the poorer soil which enabled them to reach the relatively less mobile K in the soil.

The uptake of nutrients by the seedlings was highest for N, followed by K and P in that order. The higher nutrient uptake by T85/799 × Pa7/808 and T79/501 × ALPHA B 36 may be related to their higher root to shoot ratios which enhanced better absorption of the nutrients (Table 3). The most important nutrient element limiting the production of cocoa in Ghana is P (Smith & Acquaye, 1963), though its requirement by the

crop is lowest in relation to the other major plant nutrients. In this study, a significant positive relationship was observed for dry matter yield and P concentrations of the seedlings in the relatively fertile soil (Table 6). The significance of this relationship is that for better seedling growth and establishment in the field, P fertilizer may be necessary.

### Conclusion

Growth and nutrient uptake among the varieties were better in the relatively fertile soil than in the poor soil. The growth patterns were similar, but the highest growth was recorded for T85/799 × Pa7/808. Dry matter yield and nutrient uptake were also highest in T85/799 × Pa7/808. The uptake of nutrients by the varieties was in the order N>K>P in both soils. The higher root to shoot ratios of T85/799 × Pa7/808 and T79/501 × ALPHA B 36 may have contributed to their efficient nutrient

TABLE 5

*Total Nutrient Uptake (g) by Cocoa Seedlings at 12 Months After Planting*

Soil variety	Relatively poor (m)			Relatively fertile (m)		
	N	P	K	N	P	K
T85/799 × Amel	3.65	0.312	0.693	3.92	0.390	0.546
T79/501 × T85/799	3.05	0.256	0.908	3.38	0.319	0.451
T85/799 × Pa7/808	6.29	0.397	1.397	4.46	0.478	0.609
APA 5 × Pa7/808	4.35	0.307	0.982	3.27	0.283	0.483
T60/887 × Pd 15	4.87	0.267	0.958	3.36	0.406	0.412
T79/501 × ALPHA B 36	6.07	0.385	0.952	5.58	0.867	0.725
Mean	4.71	0.321	0.982	4.00	0.457	0.538
SE	0.52	0.024	0.094	0.37	0.087	0.047

TABLE 6

*Correlation Coefficients (r) for the Relationship Between Dry Matter Yield and Nutrient Content of 12-month-old Cocoa Seedlings*

Soil	Nutrients				
	N	P	K	Ca	Mg
Relatively poor	+0.69	+0.35	-0.10	-0.58	-0.44
Relatively fertile	-0.47	+0.83*	-0.48	-0.38	-0.27

\*Significant at  $P < 0.05$

uptake, and hence their higher dry matter yield. Although P was the least absorbed by the varieties, P significantly related with the dry matter yield for the varieties. Absorption of P was, however, better in varieties with relatively shorter roots. From their superiority over the other varieties in growth and nutrient uptake, T85/799 × Pa7/808 and T79/501 × ALPHA B 36 may be more vigorous in the field and probably higher yielding than the other varieties in both soils. Glendinning (1960), in his studies on the relationship between growth and yield in cocoa varieties, established a high positive correlation between pre-bearing growth rates and yield. It is, therefore, suggestive that cocoa varieties with higher root to shoot ratios may be preferable for planting on good and marginal soils in cocoa rehabilitation programmes. The application of P fertilizer may be required to ensure better growth and establishment of seedlings in the field.

#### Acknowledgement

The authors gratefully acknowledge the technical assistance of the staff of the Agronomy/Soil Science Division. They are also grateful to Mr J. K. Asiamah in the preparation of the manuscript. This paper is published with the kind permission of the Executive Director, Cocoa Research Institute of Ghana.

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