Chapter 7

Shade and nutrition

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Research and experience have shown that the effects of light and nutrition are interrelated. This means in practical terms that the shade requirements for cocoa and the response to fertilisers cannot be considered separately. Therefore the two factors, shade and nutrition, are grouped together in this chapter.

Shade

Shade and carbon dioxide assimilation

The effect of shade on cocoa is very complex. It involves reduction in light intensity, temperature and air movement and it affects relative humidity and soil moisture. Reduction in light intensity, or rather radiation, is a very important effect, as radiation is one of the main factors governing photosynthesis or carbon dioxide (CO_2) assimilation.

The relationship between radiation and CO_2 assimilation in cocoa was studied by Lemée (1955). He studied individual leaves of mature cocoa adequately supplied with nutrients and water, and found that the assimilation rate increased from 7 to 22 mg CO_2 per dm^2 per day when light intensity increased from 2 to 25 per cent of full daylight. Further increases in light intensity up to 100 per cent exposure caused little increase in assimilation rate. On bright days, however, Lemée observed a sharp decline in assimilation rate when solar radiation exceeded values between 210 and 310 Joules per m^2 per sec. This is the range in which leaves of other plants reach and maintain their maximum rate of assimilation. Lemée also found that for leaves developed in the shade this depressant effect occurred at a much lower level of radiation.

Okali and Owusu (1975) working in Ghana have reported similar findings: light saturation of individual leaves when exposed to 20 per cent full sunlight and a decline in photosynthetic rate at a light intensity greater than 30 per cent. The percentages are much lower

for leaves developed in the shade. Hutcheon (1976) found that most of the leaves studied reached light saturation at about 15 per cent full midday sunlight. Leaves from seedlings and young plants showed a decline in photosynthetic rate at higher light intensity, but leaves from vigorous trees in the field showed little or no decrease in photosynthetic rate as light intensity increased to full sunlight (equivalent to 1000 Joules per m^2 per sec). The highest photosynthetic rate of 7.5 mg CO_2 per dm^2 per hour, was found under favourable conditions in large thick green leaves and was associated with vigorous growth.

The need for shade of young cocoa

When young plants with few hardened leaves are grown in full sunlight, on sunny days all leaves are exposed to high levels of radiation. This reduces photosynthesis as shown above. It is thus not surprising that young plants will only grow well under shade. Shade also affects temperature and relative humidity around the plant which in turn affects transpiration. There is ample evidence that young cocoa plants are very sensitive to moisture stress and, when exposed, can only thrive when provision is made for a continuous water supply and restricted air movement (Cunningham and Burridge 1960, Alvim 1977); Hutcheon (1976) found moisture stress in young plants grown in containers even when the roots were kept well watered. This moisture stress resulted in closure of the stomata during periods of high radiation causing a decline in the photosynthetic rate. Plants with adequate nutrition had, however, a higher photosynthetic rate which declined more gradually in saturating light than plants with low nutrition. Hutcheon (1973) also showed that plants of different cultivars differed in their ability to grow in full sunlight. Scavina 6 seedlings tolerated full sunlight whilst Amelonado seedlings did not. All these results indicated that generally speaking young plants need some degree of shading.

The shade requirements of young plants for optimum growth, and later on for cropping, change with time. This is to be expected as the stage at which there is a single layer of leaves gradually changes to a closed canopy with many layers of leaves. This process is nicely illustrated by the results of a shade and fertiliser experiment in Trinidad (Evans and Murray 1953). The trial had five light intensities, 15, 25, 50, 75 and 100 per cent full light, each carrying a factorial fertiliser layout of presence and absence of N, P and K. During the first 12–18 months in the field, growth was best at light intensities between 30 and 60 per cent light and fertilisers produced little effect. As the plants grew in size the effect of fertiliser applications became increasingly evident at higher light intensities. When the plants came into bearing in the third year the effects of shade and fertiliser and their interaction became evident and are shown in Fig. 7.1, which compares yields of plants receiving NPK and the control treatment. At 15 and 25 per cent light yields are low and fertilisers have little effect. Up to 50 per cent light the yield and response to fertilisers increases, but at light intensitites above this level yield falls in the absence of fertilisers and increases with fertilisers to its maximum at 75 per cent light (Murray 1954).

This means in practical terms that on non-fertilised, chemically poor soils, cocoa gives highest yield under shade, but on fertile soils or with adequate fertiliser, well established cocoa yields most with little or no shade.

Light intensity also affects the shape of young cocoa trees. Trees grown with little or no shade have a bushy appearance: short internodes, small leaves, a low jorquette and a dense crown. From the management point of view this shape is not desirable, and this is a further and important reason why young cocoa is grown under shade.

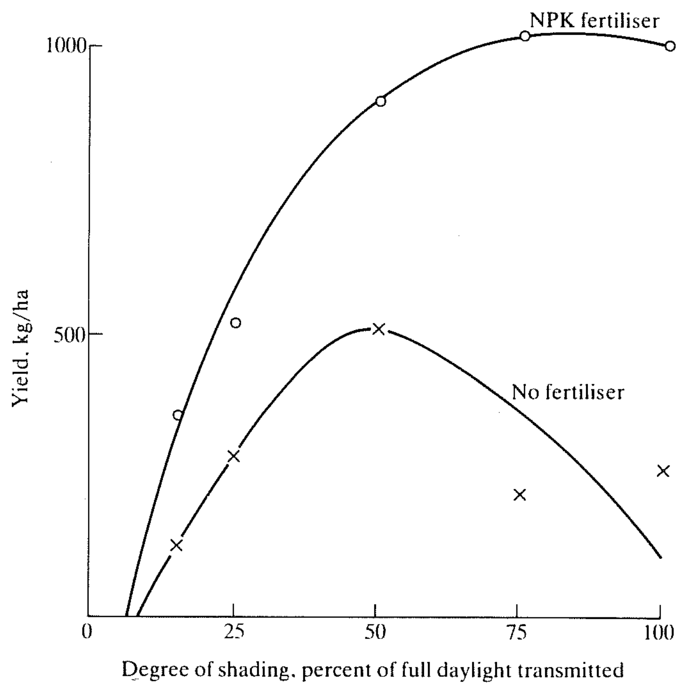


Fig. 7.1 Effect of fertiliser application on yield of cocoa grown at different light levels. SOURCE: Murray (1975).

The need of shade for mature cocoa

The relationships between shade and nutrition, which apply to cocoa during the first years of bearing, apply also to mature cocoa. This was shown in a large shade and manurial field experiment in Ghana. This trial was laid out on Amelonado cocoa, spaced at 2.4 × 2.4 m, and under *Gliricidia* shade. When the cocoa was ten years old, shade and fertiliser treatments were applied. Removal of shade gave a large increase in yield which was further augmented by fertilisers. The yields for the four treatments over a fourteen-year period are shown in Fig. 7.2.

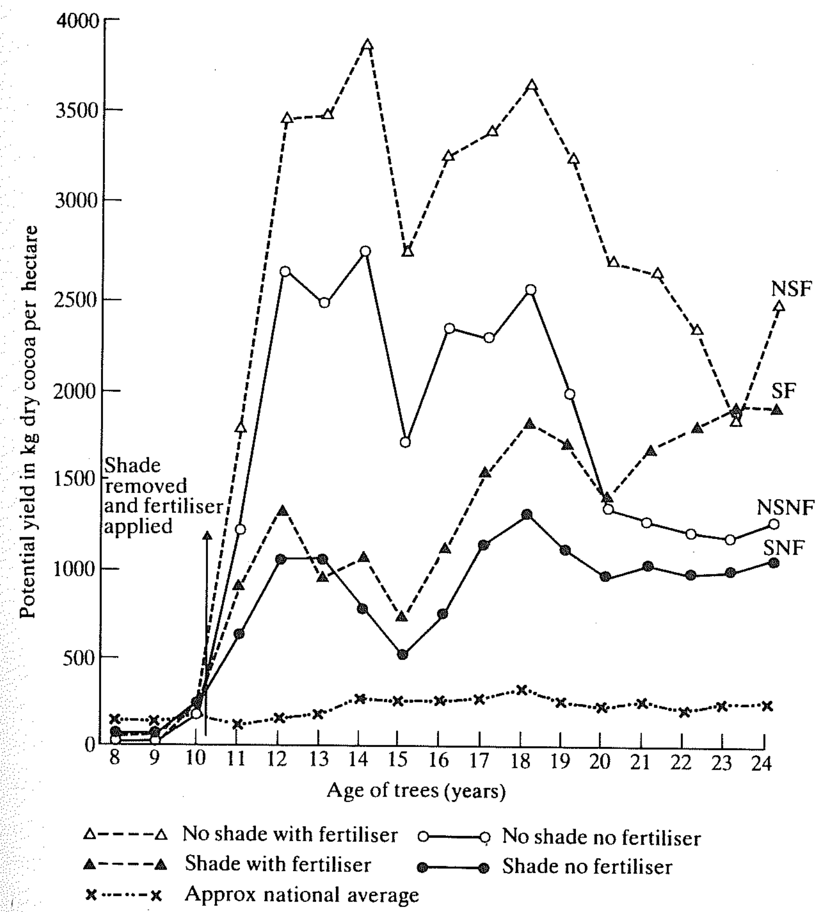


Fig. 7.2 Effect of shade removal and fertiliser applications on yield of Amelonado cocoa in Ghana. SOURCE: Ahenkorah *et al.* (1974).

The original shade was apparently too heavy for high yields as well as for full exploitation of the nutrients already present in the soil or added in fertilisers, and this resulted in low yields. In other words light was the main factor limiting yield. When this limitation was removed the supply of nutrients from the soil became the next limiting factor which was in turn amended by application of fertilisers.

The observations in this shade and manurial trial were continued for a long time with valuable results, as they show that after about ten years the yield of the unshaded cocoa started to decline while the yield of the plots with shade and fertilisers showed an upward trend. This decline was attributed to several factors: nutritional stress in the trees, a depletion of exchangeable bases in the soil, an unfavourable change in the environment by removal of neighbouring forest, and high insect incidence involving dieback (Ahenkorah *et al.* 1974).

Shade removal and pod production

The reason why shade reduction brings about higher yields was studied in Ghana in two field experiments (Hurd and Cunningham 1961, Asomaning *et al.* 1971). Their data and those of Boyer (1974) in Cameroon show that reduction or removal of shade increases the production of leaves (Table 7.1) and greatly stimulates flowering. In the first shade and manurial trial in Ghana mentioned above the increase in yield following shade removal depends almost entirely on flowering (Table 7.2).

In the absence of shade the conditions were more favourable for pollination and subsequent pod growth, but the percentage of flowers set and the percentage of pods lost by cherelle wilt remained unchanged. The second shade and manurial trial in Ghana showed a similar effect on flowering and pollination but the main reason for the yield increase in the no-shade treatment was a 10 per cent reduction in cherelle wilt. As competition between cherelles for carbohydrates is an important factor causing cherelle wilt, the combination of a greater leaf area and a higher light intensity in unshaded cocoa, which both favour carbohydrate production, could well be another important factor causing the yield increase following shade removal.

Table 7.1 *Effect of shade conditions on mean annual leaf development of mature cocoa in Cameroon over the period 1967–1971*

	No. of leaves per tree	*Leaf surface area per tree (m^2)*
Moderate shade	3,160	52.87
Light shade	3,386	54.14
No shade	4,096	59.79

SOURCE: Boyer (1974).

Table 7.2 *Mean estimated flowering, fruit setting and pod development per tree (during 1958) in the first shade and manurial trial in Ghana*

Treatment	*Flowering No.*	*Setting No.*	*%*	*Cherelles wilting No.*	*%*	*No. of pods harvested*
Shade	973	67.5	6.9	53.9	79.9	12.7
Shade, fertilisers	1,170	72.1	6,2	58.1	80.6	14.4
No shade	2,649	159.5	6.0	114.1	71.5	39.1
No shade, fertilisers	3,331	232.0	7.0	179.9	77.5	48.6

SOURCE: Hurd and Cunningham (1961).

Summary of shade requirements

Reviewing the above information it can be said that young cocoa plants need some degree of shading in the nursery and also during the first 2–3 years in the field. The shade is not only needed to reduce light intensity but also to buffer the micro-environment so that excessive moisture stress in the young plants is avoided. When the trees grow older and their canopies are sufficiently developed to provide some self-shading, and when later on the canopies of neighbouring trees meet, the need for shade decreases and yields are usually higher when trees are grown with little or no shade. The larger leaf area and the higher photosynthetic activity of unshaded cocoa, which results in higher pod production, can only be maintained when trees are well provided with nutrients. For this reason fertiliser application is usually needed in lightly shaded or unshaded cocoa.

Complete removal of shade gives rise to high yields which are, however, difficult to maintain over long periods. The decline which follows has various causes, insect damage involving dieback being an important one. The decline is not limited to yield but also affects the general condition of the cocoa trees. It seems that shade removal shortens the economic life of cocoa trees considerably and that shade is an effective means of controlling conditions which lead to premature decline of yields. Situations where climate and soil allow cocoa trees to be unshaded are rather limited and the approach to high yields by shade reduction or removal should be made gradually.

Shade trees

The types of trees used as temporary and permanent shade for cocoa are fully discussed in the chapter on establishment, so only certain aspects of soil fertility and nutrition will be reviewed here. As mentioned earlier young cocoa trees do best under fairly heavy shade, which is already present when planting is done under thinned forest or mature coconuts. If the area has been clear-felled shade must not only be planted well in advance of the cocoa but also soon after clearing the forest in order to limit losses in soil organic matter and nutrients and to protect the soil surface against radiation. mechanical impact of rain and erosion. After the establishment of cocoa, shade trees may contribute to the maintenance of soil fertility by uptake of nutrients originally present and washed down into lower soil layers, returning them in the litter to the soil surface. Leguminous trees are of special interest because of their nitrogen fixing capacity. Adams and McKelvie (1955) found that on a typical, shaded cocoa farm in West Africa, the forest tree shade contributed some 5 tonnes of litter per ha per year containing 79 kg N and 4.5 kg P. This illustrates the important role shade trees can have in maintaining soil fertility and strengthening the nutrient cycle of a stand of cocoa which is discussed in the next section.

Nutrition

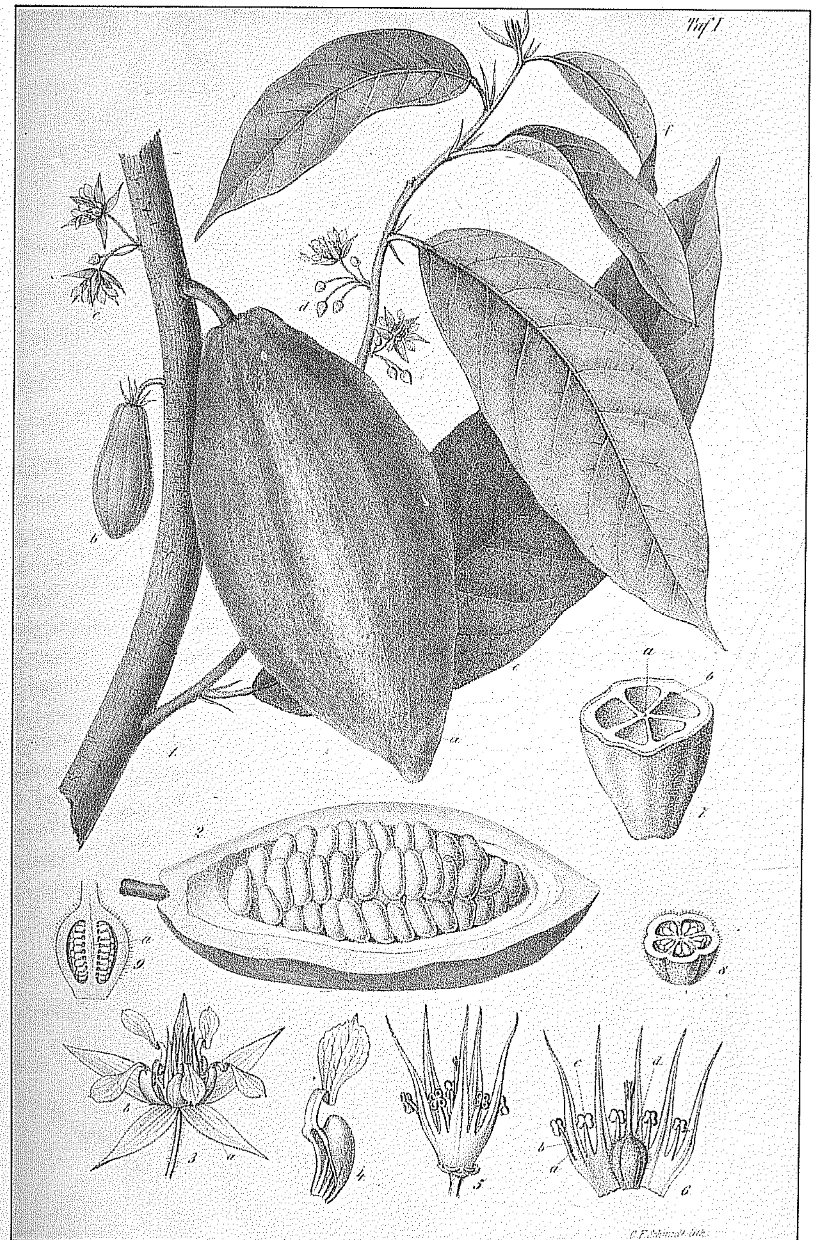
Nutrient requirements

The nutrient requirements of cocoa can be assessed by chemical analysis of trees in different stages of development and by chemical analysis of the crop. Table 7.3 shows, for example, that about 200 kg N, 25 kg P, 300 kg K and 140 kg Ca are needed per ha to build up the frame and the canopy of the trees before pod production starts. Considerable quantities of nutrients are immobilised in the vegetative parts during the early years of production. These quantities decrease later on and when the trees are fully developed they are exceeded by those annually removed in the crop. Table 7.4 shows

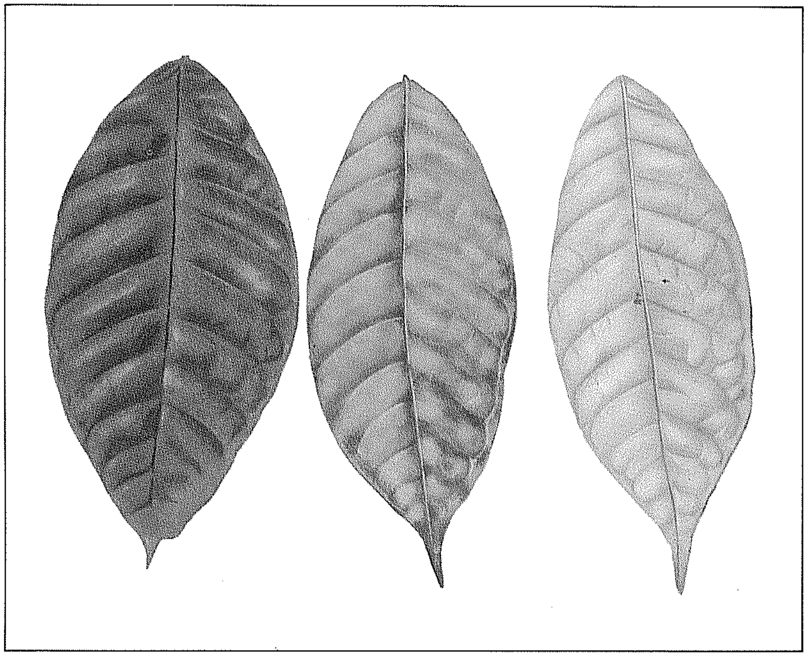
Table 7.3 *Estimation of nutrient requirements of cocoa plants at different stages of development from whole plant analysis (based on 1,075 trees per ha)*

Stage of plant development	*Range of age of plants (months)*	*Average nutrient requirement in kg per ha*						
		N	*P*	*K*	*Ca*	*Mg*	*Mn*	*Zn*
Seedling (nursery)	5–12	2.4	0.6	2.4	2.3	1.1	0.04	0.01
Immature (field)	28	136	14	151	113	47	3.9	0.5
First year production (field)	39	212	23	321	140	71	7.1	0.9
Mature (field)	50–87	438	48	633	373	129	6.1	1.5

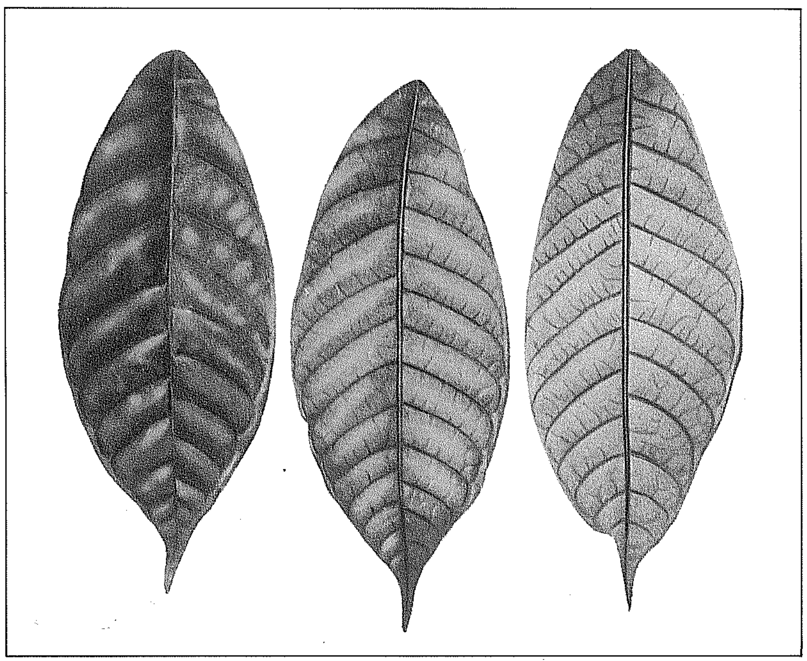
SOURCE: Thong and Ng (1978).



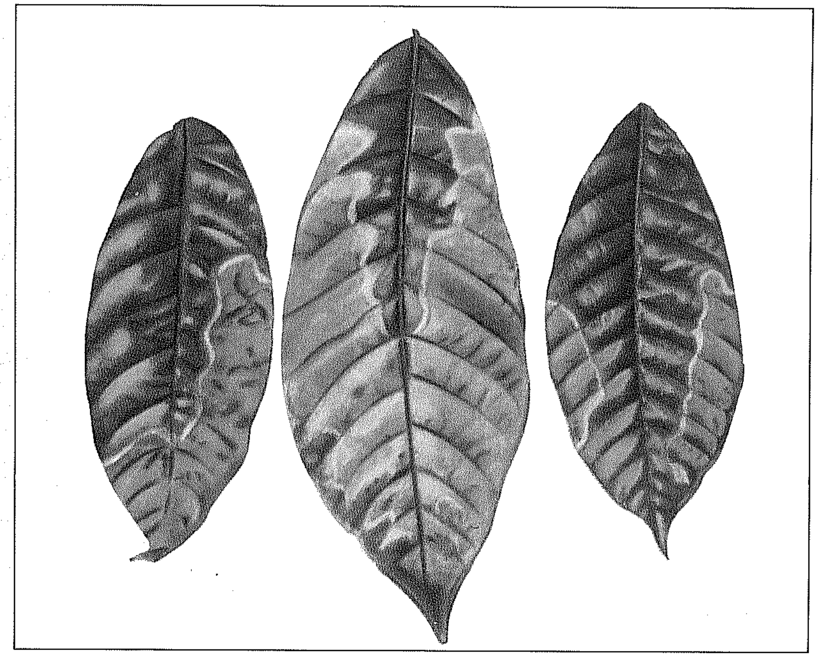
I. Botanical illustration from *Der Cacao und die Chocolate* by Alfred Mitscherlich, Berlin 1859. The original lithograph was by Carl Friedrich Schmidt.



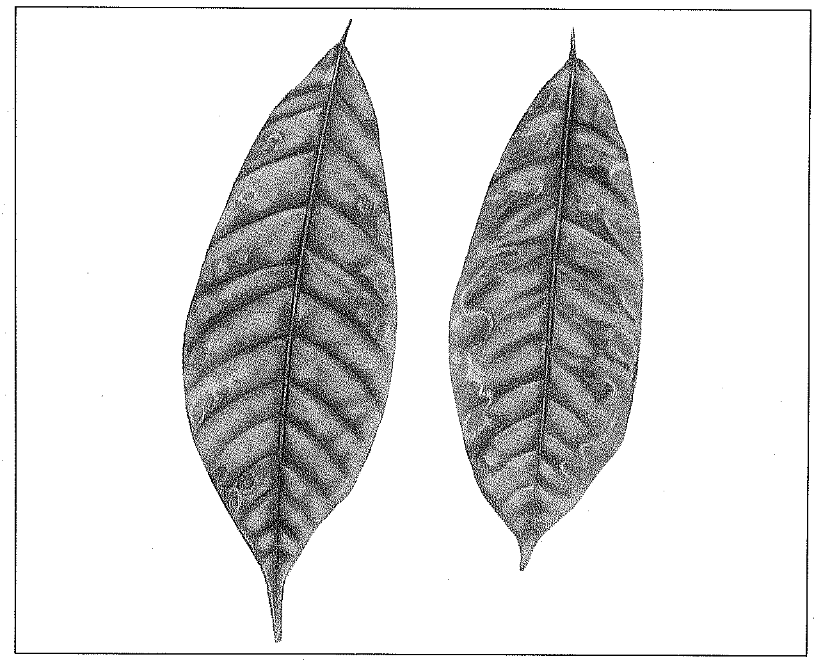
II. Symptoms of nitrogen deficiency. Three leaves showing different degrees of deficiency. The older leaf on the left shows tip scorch to a small degree.



III. Symptoms of iron deficiency.

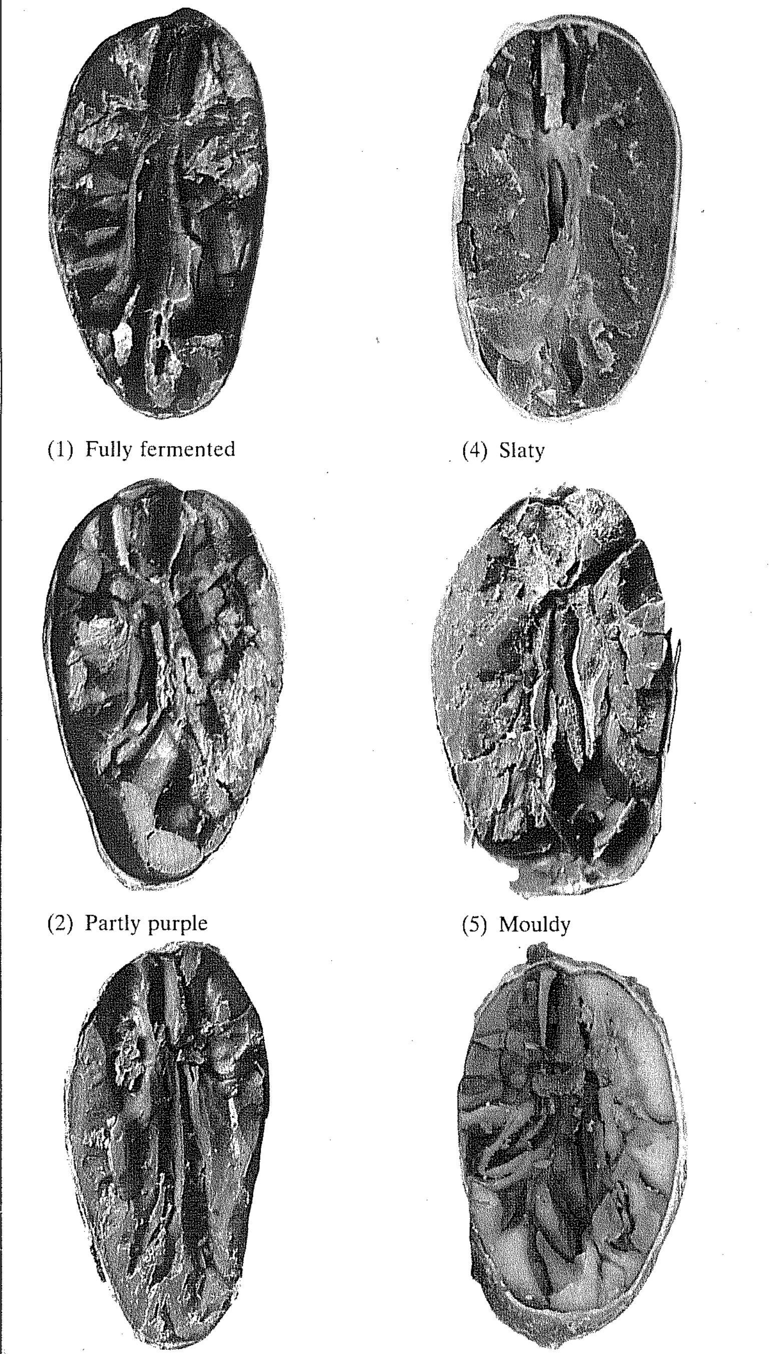


IV. Symptoms of potassium deficiency.



V. Symptoms of calcium deficiency.

SOURCE: (II–V) Institut de Recherches du Café, du Cacao et autres plantes stimulantes.



(1) Fully fermented (4) Slaty

(2) Partly purple (5) Mouldy

(3) Fully purple (6) Well fermented Criollo

VI. Cocoa beans showing defects and degree of fermentation: Nos (1)–(5) Forastero beans.
SOURCE: (1), (2), (3), (5) and (6) Cadbury Ltd. (4) W. H. Chick, Dunlop Estates Bhd.

Table 7.4 *Nutrients (kg) removed in a crop of 1,000 kg dry cocoa beans*

Country	*Type of Cocoa*	*Beans*					*Husks*					*Total*				
		N	*P*	*K*	*Ca*	*Mg*	*N*	*P*	*K*	*Ca*	*Mg*	*N*	*P*	*K*	*Ca*	*Mg*
Nigeria	Amazon	22.8	4.0	8.4	—	—	17.0	2.3	77.2	—	—	39.8	6.3	85.6	—	—
Nigeria	Amelonado	22.9	3.9	8.5	—	—	15.4	1.8	68.4	—	—	38.3	5.7	76.9	—	—
Cameroon	Trinitario	19.2	4.4	10.6	0.9	3.2	15.0	1.9	62.0	7.3	3.6	34.2	6.3	72.6	8.2	6.8
W. Malaysia	Amazon	20.4	3.6	10.5	1.1	2.7	10.6	1.3	43.3	3.8	2.5	31.0	4.9	53.8	4.9	5.2

SOURCE: Boyer (1973), Omotoso (1975), Thong and Ng (1978).

that a crop of 1,000 kg dry beans removes about 20 kg N, 4 kg P and 10 kg K and if the method of harvesting involves the removal of pod husks from the field the amount of K removed is increased more than five-fold. Beans from different origins vary less in chemical composition than do the husks, indicating that the husks are more strongly affected by the environment, e.g. nutrient supply and variety, than are the beans.

An almost complete picture of the nutrient cycles and requirements of a mature planting can be obtained from the nutrient balance shown in Table 7.5. It refers to a thirty-year-old, unshaded Trinitario cocoa planting in Cameroon with a density of about 1,000 trees per ha and an average annual yield of 700 kg dry beans per ha. Most of the nutrients taken up by the trees are returned to the soil in litter and by rain dripping from the leaves. When the annual return is expressed as a percentage of total uptake, the lowest value is about 50 per cent in the case of P and the highest figure about 90 per cent for Ca. At this age, the amounts of nutrients immobilised in the vegetative parts of the trees are unimportant. The annual uptake of N, K and Ca is high in absolute terms while the uptake and annual removal of P and K is also high relative to their reserves in the main rooting zone, i.e. in the 0–20 cm soil layer.

Table 7.5 *Nutrient balance (kg per ha) for thirty-year-old Trinitario cocoa in Cameroon*

Process		*N*	*P*	*K*	*Ca*	*Mg*
Annual removal from nutrient cycle	Yield (700 kg dry beans per ha)	24.0	4.4	51.0	5.8	4.8
	Immobilization	3.5	0.1	5.0	5.5	1.5
Annual return of nutrients	Rainwash	6.3	1.3	101.0	34.6	32.0
	Litter	52.5	3.8	38.0	89.0	26.2
Total annual uptake		86.3	9.6	195.0	134.9	64.5
Soil reserve (kg per ha)*	0–20 cm	3,709	52	76	3,100	578
	0–100 cm	10,640	245	240	7,280	2,340
Nutrients annually added in rainfall (about 1,700 mm)		12	1.7	12.0	3.8	1.5
Nutrient losses from the soil by leaching		n.d.†	n.d.	n.d.	n.d.	n.d.

* Total N, available P and exchangeable K, Ca and Mg.
† Losses not determined. In view of periods of very high rainfall, e.g. in September and October, nutrient losses by leaching are likely considerably to exceed the additions in rainfall.
SOURCE: modified after Boyer (1973).

Methods for assessing nutrient requirements

Soil analysis

In the previous section it was shown that nutrient requirements of cocoa plants in different stages of development can be estimated from plant analysis and the analysis of pods and beans. It is not, however, possible to arrive at precise fertiliser recommendations without knowing the short and long-term nutrient supply in the soil. Thus the first stage in determining fertiliser requirements is soil analysis. Its value increases greatly when data from fertiliser trials on the soils analysed are also available. In that case soil data can not only help to explain fertiliser responses but also to predict responses elsewhere. Only when numerous fertiliser trials and soil data are available, can soil analysis be developed as a satisfactory diagnostic method for fertiliser use. In most cocoa-growing countries this stage has not yet been reached. Over the years, however, enough data have become available to establish some relationships between soil analysis data and growth and production of cocoa trees. These are discussed under the heading 'Fertiliser trials'.

A new mode of interpretation of analysis of cocoa soils was introduced by Jadin (1972, 1975, 1976). This method is based on the concept that, in the soils of Ivory Coast, there are optimal relationships dependent on pH between the sum of exchangeable K, Ca and Mg and total N, between these three bases, and between total N and total P. On empirical grounds criteria for high soil productivity were adopted as shown in Table 7.6.

Fertiliser requirements for different sites were calculated from the difference between nutrient levels in the soil and the optimal levels together with the relationships given above using correction factors where needed. As no yield responses to N had been observed in the Ivory Coast, the existing levels of N in the soil were used as a basis and the levels of P and of exchangeable bases adjusted accordingly. The cocoa area of the Ivory Coast was divided into seven zones on the basis of the calculated fertiliser needs and on isohyets, each zone having its own fertiliser recommendation. Three zones required P

Table 7.6 *Empirical criteria for high productivity of cocoa soils in the Ivory Coast*

pH	*%N*	*Sum of exchangeable K + Ca + Mg in me per 100 g soil*	*Ratios*	
			K : Ca : Mg	*N : P_2O_5*
5.0	1.02	3.0	8 : 68 : 24	2 : 1
5.5	1.18	4.4	8 : 68 : 24	2 : 1
6.0	2.44	15.8	8 : 68 : 24	2 : 1

SOURCE: Jadin (1975, 1976).

and Ca, two zones P, K and Mg, one zone P, K and Ca and the remaining one P and K, showing that P is required in all zones. With the amount of the annual fertiliser dressing fixed at 700 g per tree, in some sites it will take as long as five years before the soil adjustment is completed and maintenance manuring can be introduced.

So far, the results of pot experiments and preliminary field trials have been encouraging. It seems, however, likely that the criteria may need further adjustment when more data from field trials become available; while a study of the distribution of P over the different chemical fractions in the soil (Wessel 1971) indicates that a more sensitive criterion than total P has to be introduced. The optimal ratio of 8:68:24 for K:Ca:Mg is probably peculiar to soils of the Ivory Coast and possibly also of a large part of West Africa. In Brazil, however, the importance of Mg was stressed which is reflected in a recommended Ca:Mg ratio of 0.3:1.0 and (Ca + Mg):K ratio between 17 and 25 (Morais and Cabala-R 1971, Morais *et al.* 1975).

Leaf analysis

This technique aims at assessing the nutrient status of the plant from the quantities of the nutrient elements found in the leaf. It has an advantage over soil analysis in that concentrations of nutrients actually taken up by the plants are measured instead of concentrations of soil nutrients which are assumed to be available to the plant. Leaf analysis is especially attractive for use in perennial crops as the current nutrient status can be assessed, adjusted if necessary, and the effects of this adjustment can be followed in subsequent samples. For a number of crops the technique has been developed to the stage at which quantitative recommendations for fertiliser use can be made. With cocoa, in spite of a great deal of research, this stage has not yet been reached.

The main problem lies in the fact that leaf age and light intensity usually override the nutritional effects on leaf composition except when there are marked deficiencies. In the young, fully expanded cocoa leaf levels of N, P and K are high and they decrease with age while the concentration of Ca and to a lesser extent Mg increases with time. This is in itself a normal phenomenon but it implies that nutritional effects can only be detected when leaves of the same age are sampled. The real problem is, however, that the age of a cocoa leaf cannot be determined from its position on the twigs and branches. The young leaves found at the end of the branches are not necessarily of the same age, as not all branches flush simultaneously; furthermore there are differences in the rhythm of flushing between individual trees and between groups of trees. The second problem is that an increase in light intensity generally lowers the N and K concentrations and raises the Ca concentration but has

little effect on the P and Mg concentrations. Differences in N and K levels in leaves of the same age may thus be due to differences either in nutrient supply or in light intensity.

These problems were studied by Wessel (1971) in Nigeria who found that light and age effects can be largely eliminated by correcting nutrient concentrations of leaves for regression on dry matter. This is based on the fact that in 4–10-week-old leaves linear

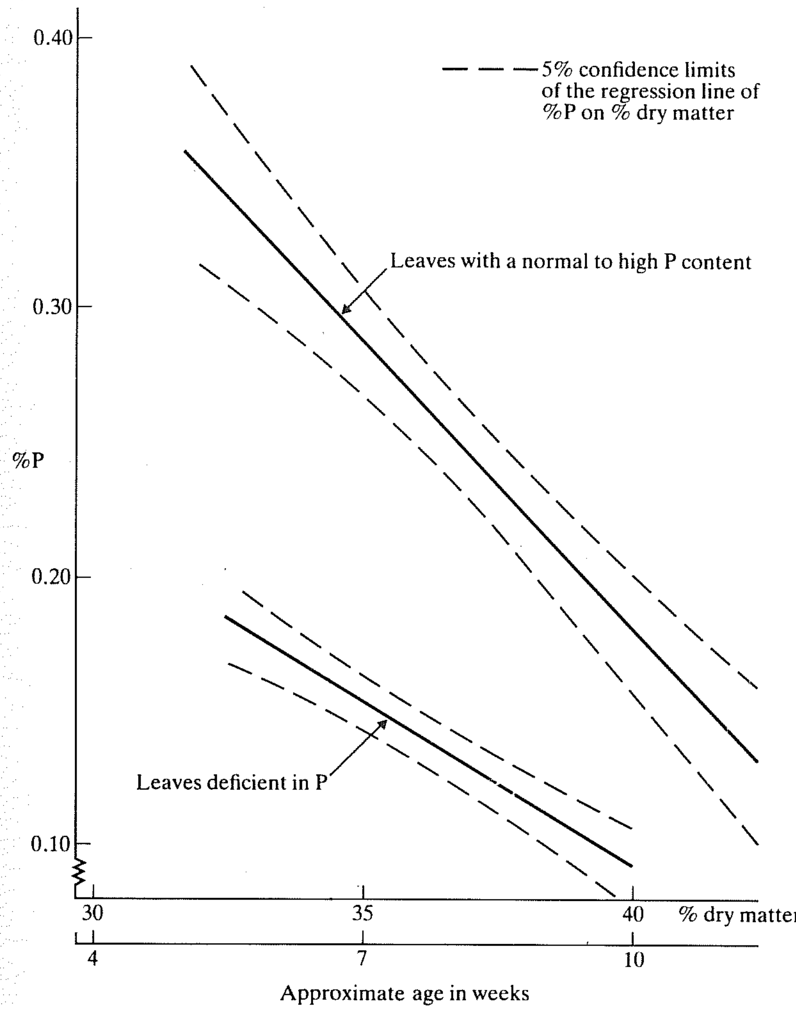


Fig. 7.3 The relationships between the phosphate and dry matter content of cocoa leaves on soils with an adequate and inadequate supply of available phosphate. SOURCE: Wessel (1971).

relationships exist between concentrations of P, K and Ca and the dry matter content, and that the dry matter content itself is related to age and light intensity. As to leaf sampling it was found that the characteristic colour change of the petiole can be used to estimate the age of young leaves and to distinguish leaves of different flushes.

These findings have considerably improved precision in detecting nutrient deficiencies. Figure 7.3 shows the relationship between P concentration and the dry matter content of leaves of P-deficient and non-P-deficient cocoa which makes it possible to use a wide range of P concentrations to assess the P nutrition of trees. When, for example, leaves of different trees are found to have P concentrations of 0.30 and 0.18 per cent, corresponding with 34 and 40 per cent dry matter respectively, it may be concluded that in both cases P supply is adequate, and that the difference in P concentration is only due to a difference in leaf age. If, however, these concentrations of P were found in leaves both with 34 per cent dry matter, the difference in P concentrations is clearly caused by a difference in P nutrition.

Despite these achievements leaf analysis is still of limited value. In the first place there is the problem of sampling. Although leaves of a suitable age can be identified, they are only available at certain periods of the year and they can only be taken from trees and fields with the same flushing rhythm. Sampling is difficult when trees are tall. In the second place there is a fundamental problem that leaf nutrient concentrations in the normal range do not provide the information needed for a quantitative fertiliser programme. Therefore the conclusion is that leaf analysis can only be used in cocoa to detect deficiencies, or an imbalance in nutrition or trends in nutrient supply, or when several years' data from the same planting are available.

Both Loué (1961) and Murray (1967) have given concentrations of major elements for normal and deficient leaves. These have been summarised in Table 7.7. Although the authors do not specify the age of the leaves, the figures and ratios between elements suggest

Table 7.7 *Nutrient concentrations in normal and deficient cocoa leaves*

Nutrient	*Criteria according to Loué (1961)*			*Criteria according to Murray (1967)*		
	Normal	*Moderately deficient*	*Severely deficient*	*Normal*	*Low*	*Deficient*
N	2.35–2.50	1.80–2.00	<1.80	>2.00	1.80–2.00	<1.80
P	>0.18	0.10–0.13	0.08–0.10	>0.20	0.13–0.20	<0.13
K	>1.20	1.00–1.20	<1.00	>2.00	1.20–2.00	<1.20
Ca				>0.40	0.30–0.40	<0.30
Mg				>0.45	0.20–0.45	<0.20

SOURCE: Wessel (1971).

Table 7.8 *Concentrations of minor elements for normal and deficient leaves*

	Normal range (ppm)	*Deficiency range (ppm)*
Fe (iron)	65–175	50
Zn (zinc)	30–65	15–20
B (boron)	25–75	8.5–11

SOURCE: de Geus (1973).

that Murray's figures refer to 5–10-week-old leaves and Loué's figures to somewhat older leaves. The figures in Table 7.7 can only be used as a general guide and the figures for normal leaves should not be considered as critical values for an adequate nutrient supply.

Finally, concentrations of minor elements, sometimes reported to be in short supply in cocoa fields, are given in Table 7.8.

Visual symptoms of mineral nutrients

Visual symptoms of mineral deficiency can help in the assessment of fertiliser requirements, be it only qualitatively. It is of course essential that the elements causing specific symptoms are properly identified. For this purpose cocoa has been grown in sand and water cultures deficient in each of the nutrients in turn. The visual symptoms produced on the plants have been described and illustrated by Maskell *et al.* (1953), Lockard *et al.* (1959) and Loué (1961). The first paper also covers toxic levels of certain elements. On the basis of these studies Murray (1975) made a simple key for identification of symptoms:

1. *Symptoms more or less general on the whole plant*:
   Element deficient – nitrogen, sulphur, phosphorus.
   Element toxic – boron.
2. *Symptoms confined to, or at least more pronounced in, the older leaves*:
   Element deficient – calcium, magnesium, potassium.
   Element toxic – aluminium, chlorine, iron.
3. *Symptoms confined to, or more pronounced in, the younger leaves*:
   Element deficient – iron, manganese, copper, zinc, boron, molybdenum, calcium.
   Element toxic – zinc, manganese, copper.

These symptoms are fully described in Appendix 1 and some are illustrated in colour plates II – V.

Field trials

The field experiment is the basic method of investigating nutrient requirements. Plant responses indicate whether the supply of nutrients from the soil is adequate and if not, which nutrient and how much of it should be added. Statistically laid out fertiliser trials of perennial crops are expensive. They have to last many years as it may take several years before effects show up and these vary in magnitude with age and development of the crop, external conditions and the length of the treatment period. This implies that over a long period good growing conditions should be provided, including adequate pest and disease control, to make accurate measurement of yield responses possible. Fertiliser trials require much space, especially as double guard rows are needed. Variability of yields is often a problem, especially when trials are conducted in smallholder's cocoa fields, which often consist of randomly planted trees of different ages. The consequences of this variability in yield for designs of fertiliser trials with cocoa was studied by Cunningham and Burridge (1959) and they arrived at the following recommendations:

1. A minimum plot size of sixteen trees for uniformly spaced cocoa and plots of about twenty-five trees for randomly planted cocoa;
2. Logarithmic transformation to obtain normally distributed yields in small plots of young cocoa;
3. Reduction in variability and hence in the required replication by calibration of trees and analysis of co-variance.

For calibration, pre-treatment yields are normally used. When these are not available tree girth measurements might be used. Elimination of variation is greatly improved when results of paired seasons are used to adjust post-treatment yields. The validity of these recommendations was later confirmed in long-term fertiliser experiments in farmers' cocoa fields in Nigeria (Wessel 1971).

Results of fertiliser trials

Trials on young cocoa

Cocoa in the nursery

The growth of nursery seedlings and their response to fertilisers is profoundly influenced by the soil used for filling the nursery bags. When chemically poor soils are used, positive responses to fertilisers can be expected. As young cocoa plants are very sensitive to nutrient imbalances and nutrient toxicity, very low rates and frequent applications are needed. Fortnightly applications, from the second month after sowing onwards, gradually increasing from 0.5–2.0 g urea or 1–3 g NPKMg fertiliser per seedling were successfully used in Malaysia (Shepherd, 1976). Mixing fertilisers with the potting medium is another possibility. Recommended rates are low, of the order of 1 kg NPKMg fertiliser per 250 kg moist soil.

Cocoa in the field

Only limited data are available from trials on young cocoa. These indicate:

1. That usually only small amounts of N fertilisers are needed for cocoa planted on soils cleared from forest except when the parent material of the soil is very poor;
2. That on less fertile soils application of fertilisers in the planting hole e.g. rock phosphate, and on acid soil also lime, may stimulate growth provided that fertilisers do not contain N;
3. That a larger response is obtained when fertilisers are frequently applied in small quantities than when the same amount is given in one or two applications per year;
4. That response to fertilisers, especially nitrogen, depends on the light intensity under which the trees are growing.

Trials on mature cocoa

Systematic research on fertiliser requirements of mature cocoa started some fifty years ago in Trinidad. In a large number of trials carried out between 1932 and 1939, spectacular increases in yield were sometimes obtained from phosphate and potassium fertilisers but many experiments were handicapped by the great variability of cocoa and inadequate experimental designs. These trials did show that nitrogen application had a positive effect on unshaded cocoa but no effect or a negative effect on shaded cocoa. It was not until the early 1950s that the apparent relationship between nutrition and shade was further studied in the experiment of Evans and Murray already mentioned. Similar results were later obtained in a large experiment, testing effects of shade, spacing and fertiliser also in Trinidad. In the absence of fertiliser highest yields were obtained from shaded plots. Responses to nitrogen were absent or negative in shaded, closely spaced plots and positive in unshaded and widely spaced, shaded plots (Maliphant 1965).

In Ghana, where substantial reduction in shade is always followed by severe insect attack, it was not until insect control had successfully been established in 1956, that a fertiliser trial involving shade removal could be started. The large response to shade removal, the response to fertilisers and the positive interaction between these two treatments have already been discussed. The results of this shade and manurial trial greatly stimulated research on fertiliser use on farmers' cocoa in Ghana and Nigeria. In both countries responses to phosphate were obtained, while in Nigeria responses to nitrogen were recorded on soils with a high phosphate content. The annual requirements for phosphate were low, of the order of 20 kg P per ha (see also Fig. 7.4). Residual effects indicate that, after an initial period of annual applications, phosphate can be applied less

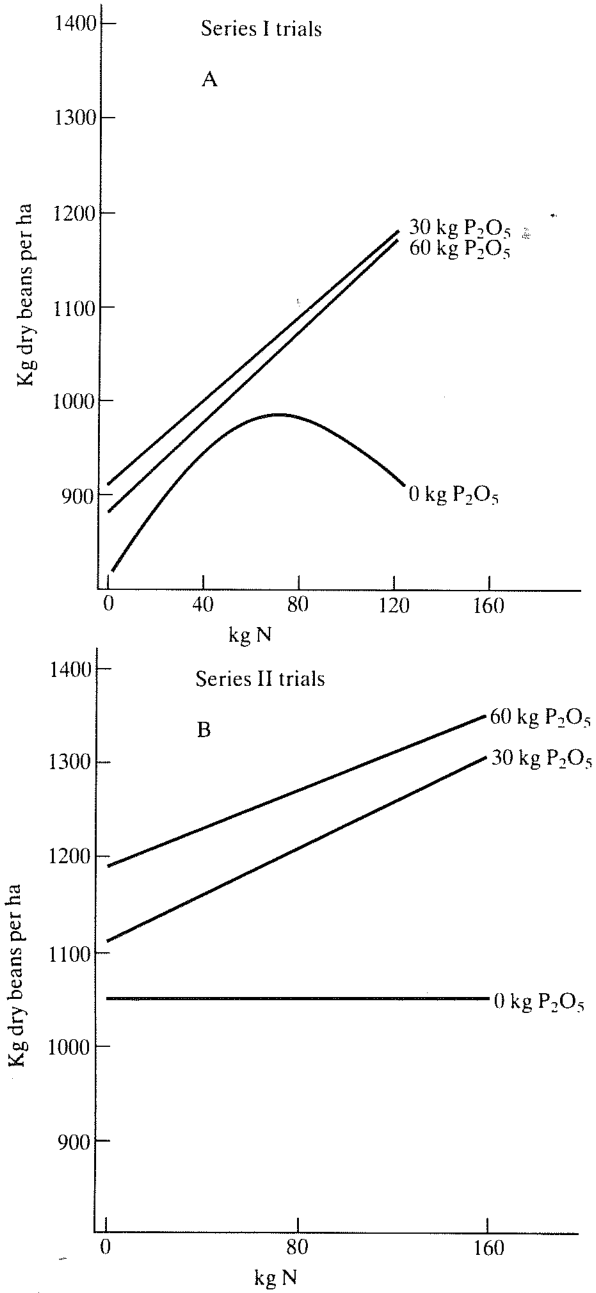


Fig. 7.4 Responses of N and P fertilisers in series I (A) and series II (B) trials on farmers' cocoa in Nigeria. SOURCE: Wessel (1971).

Table 7.9 *Effects of shade removal and fertiliser application on mature cocoa in Bahia, Brazil. Mean annual yields of twenty-one sites over the period 1964–1973 in kg dry beans per ha*

	No fertilisers	*Fertilisers*
Shade	907	1,258
No shade	1,064	1,680

SOURCE: Cabala-R. *et al.* (1976).

frequently. Experimental results from Bahia, Brazil (Cabala-R. *et al.* 1975), and the Ivory Coast (Loué 1961) indicated that, in these countries as well, phosphate is the most important nutrient limiting cocoa production.

The explanation of the almost universal response to added P is the inadequate P supply from the soil. Although the total amount of P in the soil may be rather high, the quantities held in easily available form are generally so low that even the low P requirements of cocoa trees cannot be met (Wessel 1971).

Fertiliser experiments with Amazon hybrids revealed that they require more potassium than conventional varieties. Responses of Amazon hybrids to K or PK have been reported from Malaysia, Cameroon and Ghana. In the second shade and manurial trial in Ghana which was planted with Amazon cocoa, there was a marked response to K in the absence of shade in addition to a positive response to P. The most profitable treatment was the combination of shade removal and PK application (Ahenkorah and Akrofi 1977).

In agreement with results obtained in Trinidad and Ghana, trials on 30–40-year-old cocoa at twenty-one sites in Bahia, Brazil, showed over a 10-year period much higher yields from unshaded areas and larger responses to fertilisers in the absence of shade (Table 7.9). When after three years, fertiliser applications were suspended on eight sites, marked residual effects were found in the next four years.

As the results of all these trials have been published in detail and have been summarised in reviews (de Geus 1973, Wessel 1980), the next part of this chapter will mainly focus on the conditions under which responses to fertilisers have been obtained.

Response to phosphate

Data from Nigeria have shown that responses to applied P are likely to occur on soils with less that 12 ppm available P in the top soil (0–15 cm). Soils with less then 7 ppm are very deficient and those with 7–12 ppm moderately deficient in P. In Brazil where a different soil extractant is employed criteria of 5 and 15 ppm are used. In Nigeria the P levels of the soil were well reflected in the P content

Table 7.10 *Relationship between the P content of cocoa leaves and soils, and response to P fertilisers in Nigeria*

% P in leaves		*Available P in the top soil (ppm)*	*Linear yield response in kg per ha per kg P_2O_5 applied*
Young leaves (±7 weeks old)	*Older leaves adjacent to the young leaves*		
<0.16	<0.11	<6	>3
0.17–0.20	0.11–0.13	6–10	1–3
>0.20	>0.13	>12	No response

SOURCE: Wessel (1971).

of the leaves of mature cocoa trees and related to response to P fertilisers, as shown in Table 7.10.

Response to nitrogen

Responses to applied N greatly depend on shade conditions and P nutrition. In heavily shaded cocoa N has usually no effect or a depressive effect on growth and yield.

In lightly shaded cocoa on P-deficient soils in Nigeria there was no response to N unless P was given (Fig. 7.4 B). On less deficient soils (Fig. 7.4A) low quantities of N (less than 70 kg per ha) raised yields, while higher quantities only continued to do so when P was also applied, but depressed yield when P was not given.

Soil N is not useful in predicting responses to applied N, but N concentrations in the leaves may be helpful in this respect. In Nigeria, for example, percentages of leaf N less than 1.8 are associated with a large response to N applications and percentages between 1.8 and 2.0 with small or no response to applied N. In addition the equilibrium between N and P has to be considered. In young leaves, N:P ratios normally range between 10 and 11, but a value within this range is also found in leaves which are equally N and P deficient. An N:P ratio less than 10 is, however, an indication of N deficiency while a ratio greater than 11 usually indicates P deficiency.

The soil and leaf criteria established in Nigeria are the basis for the fertiliser recommendations in Table 7.15.

Response to potassium

In Malaysia response to K was related to levels of total extractable K less than 0.40–0.55 me per 100 g soil (Mainstone and Thong 1978). K-deficient cocoa occurred in Ghana on soils with less than 0.2 me exchangeable K per 100 g of soil in the 0–15 cm layer (Acquaye *et al.* 1965).

In Brazil soils with 0.11–0.30 me exchangeable K are considered deficient and with less than 0.1 me very deficient (Cabala-R. *et al.* 1975). Low soil K levels are usually reflected in the content of the leaves. Concentrations of less than 2 per cent are an indication of deficiency. As K is rapidly transported from older to younger leaves, it is sometimes necessary to analyse not only young leaves (which are usually sampled) but also the adjacent older leaves before a deficiency can be clearly established. This is shown in Table 7.11. It can be seen that, in the K-deficient trees without deficiency symptoms, the youngest leaves have a comparatively high K content, though this still does not meet the 'sufficiency standard'.This level is reached at the expense of the older leaves from which the K was taken. In this case it is the steep gradient in K concentrations between the leaves of different ages that indicates the severity of the deficiency.

Fertiliser recommendations and practices

Nursery seedlings

Because of the sensitivity of young cocoa seedlings to fertiliser toxicity there are hardly any recommendations on fertiliser use in nurseries. The rates recommended by Wyrley-Birch (1973) for use in planting bags equal approximately 1 kg of a 15:15:6:4 NPKMg compound per 250 kg of moist soil.

Young cocoa in the field

Young trees initially exploit only a small volume of soil, and therefore soil and leaf analysis are of limited value and fertiliser recommendations are of a general nature. The manuring programme for young cocoa in Sarawak (Table 7.12) gives an impression of rates and frequency of fertiliser application used at present for young Amazon hybrid cocoa under growing conditions which are favourable throughout the year. Where conditions are unfavourable during part of the year, for example, during the dry months in West Africa, lower quantities can be used.

Wessel (1971) gave a preliminary fertiliser recommendation for young cocoa in Nigeria on soils derived from metamorphic rock as shown in Table 7.13. Young cocoa established on soil cleared from forest only requires some additional N. The P status of these forest soils is adequate but has to be maintained at a satisfactory level by P applications when trees come into bearing. When soils are cleared from cocoa or arable crops, their available P reserves have usually been depleted and young cocoa will require both N and P. As the metamorphic rock soils are well supplied with K, additional K is not needed. From the third or fourth year after planting onwards, in

Table 7.11 *Comparison of the chemical composition of potassium-deficient and normal cocoa leaves in Nigeria*

	Leaf age	*% dry matter*	*%N*	*%P*	*%K*	*%Ca*	*%Mg*	*me exchangeable K per 100 g soil*
K-deficient tree without leaf symptoms	Young*	30.6	2.37	0.24	1.75	0.60	0.48	
	Medium-old	39.6	2.06	0.12	0.54	1.66	0.98	0.13
	Old	41.8	1.86	0.09	0.32	1.88	1.03	
K-deficient tree with deficiency symptoms on medium-old leaves	Young	33.9	2.56	0.30	1.17	0.50	0.41	
	Medium-old	43.8	1.75	0.12	0.23	1.60	1.23	0.10
	Old†							
'Healthy' tree	Young	31.8	1.99	0.24	2.34	1.03	0.54	
	Medium-old	38.7	1.50	0.10	1.17	1.69	0.62	0.30
	Old	40.7	1.58	0.08	1.10	2.33	0.59	

* The young, medium-old and old leaves are groups of leaves of subsequent flushes on the same branch.
† Older leaves already dropped off.
SOURCE: Wessel (1971).

Table 7.12 *Manuring programme for young cocoa in Sarawak*

Months after field planting	*Fertiliser application per point (g)*			
	N	P_2O_5	K_2O	*MgO*
1	6.4	6.4	6.4	–
4	8.5	8.5	8.5	–
8	8.5	8.5	8.5	–
12	12.8	12.8	12.8	–
18	17.0	17.0	17.0	–
24	27.3	27.3	38.5	4.5

SOURCE: Ebon *et al.* (1978).

Table 7.13 *Preliminary fertiliser recommendation for young cocoa in Nigeria*

Year	*Soils cleared from forest*	*Soils cleared from cocoa and arable crops*	*Time of application*
Year of planting	10 g N per tree	10 N + 10 g P_2O_5 per tree	½ July/ ½ September*
1st – 3rd year after planting	20–30 g N per tree	20–30 g N + 20–30 g P_2O_5 per tree	½ April/ ½ August*
4th and 5th year after planting	50–65 kg N + 35 kg P_2O_5 per ha		½ April/ ½ August÷

* Fertilisers applied in circular bands starting at 10 cm from the stem.
÷ Broadcast application.
SOURCE: Wessel (1971).

West Africa usually somewhat later, fertiliser programmes for mature cocoa are followed.

Mature cocoa

Fertiliser and liming recommendations for mature cocoa in the State of Bahia, Brazil are summarised in Table 7.14. N is always given at an annual rate of 60 kg per ha, while P and K applications are based on soil criteria discussed earlier. Liming is only recommended when exchangeable Al exceeds 0.4 me per 100 g soil. In soils with a reasonable Ca and Mg content there is no need to eliminate all exchangeable Al. It is sufficient to reduce the percentage Al saturation of the absorption complex to values below 15.

A recommendation for mature Amelonado cocoa in Nigeria grown on soils derived from metamorphic rock and yielding about 800 kg dry beans per ha is given in Table 7.15. The criteria for leaf N and P used in this table have already been discussed.

Wyrley-Birch (1973) gives as a general recommendation, not based on soil and leaf analysis criteria, for Amazon cocoa in Sabah

Table 7.14 *Fertiliser and liming recommendation for mature cocoa in Bahia, Brazil*

Fertiliser
Annual dressing of 60 kg N per ha, applications of P and K on the basis of soil criteria, rates in kg per ha.

		Available P in ppm					
		<5		6–15		>15	
		P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Exchangeable K in me per 100 g soil	<0.10	90	90	45	90	0	90
	0.11–0.30	90	45	45	45	0	45
	>0.30	90	0	45	0	0	0

Lime
Applications of dolomitic limestone in tonnes per me exchangeable Al

		Exch. Al in me per 100 g soil	
		<0.4	*>0.4*
Exchangeable Ca + Mg in me per 100 g soil	<3	Nil	1.5
	>3	Nil	1.5*

* Till the point is reached that the % Al saturation is below 15.
SOURCE: modified after Cabala-R. *et al.* (1975).

Table 7.15 *Preliminary fertiliser recommendations for mature Amelonado cocoa in Nigeria*

Cocoa	*Nutrition status*		*Annual fertiliser rate*	*Time of application*
	Soil	*Leaf**		
Severely N deficient	—	%N < 1.8 or %N 1.8–2.0 and N/P < 9	120 kg N per ha	½ April/ ½ August†
Moderately N deficient	—	%N 1.8–2.0 and N/P < 9	65–100 kg N per ha	½ April/ ½ August†
Not N deficient	—	%N > 2.0	No N fertiliser	
P deficient	Available P < 10 ppm	%P < 0.2	50–65 kg P_2O_5 per ha	½ April/ ½ August†
Not P deficient	Available P > 12 ppm	%P > 0.2	No P fertiliser	

* 5–10 week old leaves sampled in April/May. † Broadcast application.
SOURCE: Wessel (1971).

an annual use of 600 kg fertiliser per ha containing 6–10 per cent N, 8–12 per cent soluble P_2O_5, 15–18 per cent K_2O and 2 per cent MgO for cocoa yielding 1,000 kg dry beans per ha. These rates do not differ much from the earlier ones given by Hardy (1960), who gave as a general guideline for mature cocoa 50–100 kg N, 25 kg P, 85 kg K and 15 kg Mg. The quantities are annual rates per hectare, the highest N rate is meant for lightly shaded or unshaded cocoa. Amounts of this order of magnitude are actually used in high yielding plantation cocoa in Sabah and Sumatra. The fertilisers are given in two or three applications per annum. Where the husks are left in the field a lower K rate is used.

Correction of minor element disorders

The main minor element disorders in cocoa fields are zinc (Zn) and boron (B) deficiency. Iron (Fe) deficiency occurs less frequently while aluminium (Al) toxicity has so far only been found with certainty on acid soils in the State of Bahia, Brazil. The symptoms of Zn deficiency consist of foliar malformations such as 'sickle leaf' or long, narrow, sometimes twisted leaves. Zn deficiency is found in many cocoa-growing countries. It may be associated with very low levels of Zn in the soil, but it is often induced by a high pH and poor aeration of the soil, which reduces the availability of Zn. The quickest remedy is foliar spraying with a solution of 300 g of zinc sulphate and 150 g of lime in 100 litres water (de Geus 1973).

Boron deficiency is a well-known disorder in Ecuador. Symptoms include profuse vegetative growth and flowering, development of short internodes and small distorted leaves and sometimes malformation of pods. Mestanza and Lainez (1970) reported the effectiveness of monthly Solubor sprays in curing the deficiency. The sprays increased the B content of leaves from 10 to 30–50 ppm and reduced leaf symptoms. They also increased pollen germination, growth of the pollen tube, fruit setting and persistence of cherelles. Boron deficiency symptoms were also reported from Ghana and Nigeria (Omotoso 1977) and low levels of B were also found in cocoa on liparitic soils in Sumatra (Wessel and Giesberger 1975).

The symptoms of Fe deficiency are easily recognised by the pattern of green veins standing out against a pale yellow green background. Iron deficiency has been reported from Ghana where it was induced by high soil pH caused by wood ash left on the field after burning of forest trees. Iron deficiency occurs occasionally in nurseries. Spraying several times at weekly intervals with a 1 per cent aqueous iron sulphate solution is an effective way to correct the deficiency, but large scale spraying in the field is unlikely to be economic.

Aluminium toxicity has been reported in the State of Bahia, Brazil, where it occurs on chemically poor, acid soils with high levels of exchangeable Al and causes poor growth of cocoa trees (Santana *et al.* 1971). In general Al toxicity adversely affects root growth and interferes with the uptake of other elements notably Ca and P. Under laboratory conditions harmful effects on cocoa were found when the Al saturation of the absorption complex exceeded 40 per cent. In the field, however, levels of 15 per cent and higher are considered undesirable. Application of dolomitic limestone was found to be effective in decreasing the amount of exchangeable Al and in improving the growth of cocoa. Depending on the Ca and Mg content of the soil, rates of application of 1.5 tonnes dolomitic limestone for each milliequivalent exchangeable Al are recommended as shown in Table 7.14.

Nutrient sources, placement and time of application of nutrients

Nutrient sources

The effectiveness of different N, P and K sources has been investigated in field and pot experiments. As to N, Khoo and co-workers found that urea was less effective in raising cocoa yields than ammonium nitrate and they attributed this to N losses through ammonia volatilisation when urea is applied on dry litter (Khoo *et al.* 1978). The problems of N losses by ammonia volatilisation from cocoa soils has been studied by Acquaye and Cunningham (1965). They found that within one week after surface application about 20 per cent of the N had been lost when urea was used and about 1 per cent or less when sulphate of ammonia or nitrate fertilisers were used. Losses were most serious when either soil pH was greater than 7.0, soil moisture was lost by evaporation or temperatures were high. The large losses from urea suggest that other fertilisers would be preferable but as these contain less N the costs of transport and application would be greater. Losses can be reduced by applying urea when the weather and soil are cool and wet, by applying small and frequent dressings and by incorporating urea in the soil. The latter solution is probably only practical in young cocoa.

A pot experiment in Brazil showed that in acid soils rock phosphate was almost as effective as a nutrient source as triple superphosphate (de Miranda and Morais 1971). In another pot trial no difference was found between treatments with muriate of potash and sulphate of potash (Morais *et al.*, 1979).

Placement of nutrients

In young cocoa, fertilisers are placed in circular bands around the trees, the bands widening with age. When the canopy is properly closed, broadcast application is usually introduced. Various studies have been made on uptake of radioactive phosphate fertilisers placed at different depths and distances from the trunk of mature trees (Wessel 1980). The results confirm the general view that in mature cocoa fertilisers should be broadcast on the soil surface throughout the field.

Foliar application is often the most efficient way to apply minor elements that are needed only in small quantities and which may become unavailable if applied to the soil. Part of the N can sometimes be given in foliar sprays of urea, usually in combination with insecticides and fungicides.

Time of application

For young cocoa fertilisers should be given frequently in small dosages and during the first and second years in the field three to four applications should be made.

For mature trees the annual rates should be split into two or three applications. In areas with a marked dry season the appropriate time is considered to be at the beginning of the main rains, when flowering and setting of the main crop takes place and 4–5 months later when the developing crop makes its greatest demand for nutrients. In other climates suitable times may occur before the main flush period, before flowering and some two months before the peak of the main harvest.

Effect of fertilisers on the content of pods

The few observations made on the effect of fertilisers on the content of pods have produced conflicting results. In Trinidad, fertiliser treatments which increased yield gave a reduction in the weight of wet cocoa per pod (Havord *et al.* 1954). In a trial in Malaysia (Mainstone and Thong 1978) a yield response to K was found to be consistently associated with an increase in the fresh pod weight required for 1 kg dry beans. These observations suggest that factors increasing the number of pods simultaneously decrease the weight of the pod contents by reducing either the mucilage weight, or the number of beans, or the bean weight.

In Nigeria, however, N and P treatments which increased yield in the series I and II trials on farmers' cocoa, did not affect wet bean weights, but there were marked climatic effects on pod and bean values (Wessel 1971).

Organic manures and mulches

Before the advent of relatively cheap mineral fertilisers, application of pen manure and compost was a standard practice in some of the older cocoa-growing countries like Trinidad, Grenada and Sri Lanka. The application of large quantities of bulky manure has however become so expensive that this practice has virtually died out. The same applies to the use of organic mulches. Mulching is a valuable practice to conserve soil moisture, to reduce soil temperatures and to maintain and improve soil structure and chemical fertility, particularly in unshaded cocoa. Nowadays it can only be carried out economically when mulch material is available on the spot as, for example, when leguminous shrubs such as *Flemingia macrophylla* are used as temporary shade.

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Chapter 8

Maintenance and improvement of mature cocoa farms

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The cost of maintaining a cocoa farm when the trees are in bearing will have a significant impact for many years on the profitability of the cocoa farming enterprise. The annual recurring costs for the major items, weeding, pruning, pest and disease control, must be minimised commensurate with maximum production of dry cocoa. A major part of these costs is expenditure on labour. Labour usage in maintaining cocoa in a number of situations in various cocoa growing areas is considered in the chapter on labour requirements.

The systems of cocoa cultivation currently utilised by the great majority of the world's cocoa farmers are the same as those in common usage at the end of the nineteenth century. New systems of cultivation of many temperate and some tropical tree crops have been developed in the last two decades. These techniques, such as high density planting at over 2,000 trees per ha with dwarf root-stocks, have not yet been used for cocoa. Posnette (1982) discusses the relevance of some of these new techniques to cocoa cultivation. He stresses the importance of using dwarf rootstocks for high density planting of apples in England. The breeding work for apples is now directed towards producing easily propagated rootstocks that do not need supports as this would substantially reduce the capital expenditure at planting. The correct use of herbicides to eliminate all weed competition is essential and hormone sprays to improve fruit setting as well as growth retardants as a substitute for hand pruning are increasingly being utilised on apples in England. Research on such rootstocks and such chemicals has not been started for cocoa.

In a perfectly maintained farm the cocoa trees would be provided with optimal conditions for growth and yield at minimum cost. Weeds, pests and diseases would be effectively controlled; the cocoa trees would be regularly pruned for sanitary purposes and their structure controlled as necessary; shade would be correctly adjusted and appropriate fertiliser would be applied. The control of diseases and pests, including rodents, is considered in the relevant chapters, while the interaction of shade and fertiliser is dealt with in the