Cacao *(Theobroma cacao L.)*

French: Cacao; Spanish: Cacao; Italian: Cacao; German: Kakao

Crop data

Perennial tree. Harvested part: pods.

Sown directly in nursery in polybags (25 cm high, 12 cm diameter), usually arranged in double rows under shade. Planted out in the field after 7-8 months. First useful flowering occurs at 18-24 months after planting (the flowers appear on the trunk and older branches). Flowering is practically continuous, but favourable pollination periods occur about 2 months after the beginning of rainy seasons. Young fruits (called cherelles when young and pods when mature) grow slowly during first 40 days after pollination and are prone to wilting (average loss about 50 %); subsequent growth is more rapid up to 75 days; full maturity is reached in 150-180 days depending on climate. There are usually two harvest peaks (main and secondary) depending in equatorial regions on the rainfall pattern, and in sub-tropical regions (e.g. Bahia, Brazil) on temperature.

Plant density: around 950-1 330 trees/ha depending on soil fertility and climate.

Shade: temporary shade needed during first 3-4 years until closed canopy established (with fertilizers, early growth is enhanced by reducing to 75 % of full light intensity; without fertilizers, it is enhanced by reducing to light intensity of 50 %). With Upper Amazon hybrids, no permanent shade is advised except on poor soils. Shade reduces flowering and yield, and shaded cacao usually shows no response to N fertilizer. Windbreaks are preferable to shade in dry or cold areas.

Nutrient demand/uptake/removal

Nutrient demand/uptake/removal - Macro and micronutrients								
Growth stage	**Age (months)**	**Average nutrient requirements (whole plant*) - kg/ha**						
		N	P2O5	K2O	MgO	CaO	Mn	Zn
Nursery	5-12	2.5	1.4	3.0	1.9	3.3	0.04	0.01
Field:								
-immature	28	140	33	188	80	163	4.0	0.5
-first production	39	219	54	400	122	203	7.3	0.9
-mature	50-87	453	114	788	221	540	7.0	1.6
* Approx. 1 100 plants/ha Source: Thong and Ng (1978) in Wessel (1987)								

Nutrient removal in crop of 1 t/ha dry cacao beans (7 % humidity) with 1.4 t/ha husks:

Country	**Beans**					**Husks**					**Total**				
	N	**P2O5**	**K2O**	**MgO**	**CaO**	**N**	**P2O5**	**K2O**	**MgO**	**CaO**	**N**	**P2O5**	**K2O**	**MgO**	**CaO**
Cameroon	19.2	10.1	12.8	5.3	1.3	15.0	4.4	74.7	6.0	10.2	34.2	14.5	87.5	11.3	11.5
Côte d'Ivoire	22.1	6.8	9.0	2.3	0.6	13.2	4.2	51.9	9.3	4.2	35.3	11.0	60.9	11.6	4.8
Nigeria	22.7	9.2	10.1	-	-	17.0	5.3	93.0	-	-	39.7	14.5	103.1	-	-
West Malaysia	20.4	8.2	12.6	4.5	1.5	10.6	3.0	52.2	4.1	5.3	31.0	11.2	64.8	8.6	6.8
Sources: Boyer (1973), Lotode and Jadin (1981), Omotoso (1975), Thang and Ng (1978) in Wessel (1987)															

Plant analysis data

Nutrient content of near mature leaves (usually the second or third leaf of the last maturing flush is taken for analysis):

Plant analysis data - Macronutrients						
Country	**Nutritional state**	**% of dry matter**				
		N	**P**	**K**	**Mg**	**Ca**
Côte d'Ivoire	Normal	2.35-2.50	>0.18	>1.20	-	-
	Moderately deficient	1.80-2.00	0.10-0.13	1.00-1.20	0.30	0.30
	Severely deficient	<1.80	<0.08	<1.00	-	-
Trinidad	Normal	>2.00	>0.20	>2.00	>0.45	>0.40
	Moderately deficient	1.80-2.00	0.13-0.20	1.20-2.00	0.20-0.45	0.30-0.40
	Severely deficient	<1.80	<0.13	<1.20	<0.20	<0.30
Source: Loué, Murray, Spector in Snoeck,1984						

Plant analysis data - Micronutrients							
Country	**Nutritional state**	**ppm dry matter**					
		Fe	**Mn**	**B**	**Zn**	**Cu**	**Mo**
Cote d' Ivoire	Normal	100	200-500	25-40	20-60	-	-
	Moderately deficient	-	20	5	10-15	-	-
Trinidad	Normal	65-175	50-400	25-70	80-170	8-12	1.0-2.5
	Moderately deficient	-	-	-	20	8	-
	Severely deficient	50	-	10	16	4	0.5
Source: Loué, Murray, Spector in Snoeck (1984)							

In spite of much research, leaf analysis cannot be used as a basis for fertilizer recommendations but only to detect deficiencies or imbalances or trends in nutrient supply.

Soil analysis

A soil diagnostic method for fertilizer requirements has been devised by Jadin (1972, 1975, 1976, 1985). Composite soil samples are taken of upper horizons in the plantations (composite of 30 borings of 0-20 cm in each homogeneous type of soil, in the fertilized area around or between cacao trees) and their chemical analyses are compared with optimum levels as shown below, and with nutrient balances determined by observation and measurements of growth, flowering intensity and fruit set, cherelle wilt, pod development and production, number of beans per pod, pod values, and yield. Soil samples should be taken every 3-4 years in order to monitor changes.

Optimum values:

Available P (Olsen-Dabin or Olsen modified) 100 ppm

Total N in relation to sum of exchangeable bases
[(m.e. % K+Ca+Mg) + 6.15] / N %o = 8.9

Ratio between exchangeable bases as percentages of sum
K : Ca : Mg = 8 : 68 : 24

Base saturation at least 50-60 %

There is a very high correlation between Olsen-Dabin available P in the soil and flowering, as well as pod yield. Good correlations were also obtained between K application and flower set in Trinidad.

Fertilizer recommendations

As most feeder roots (80 %) are in the top 0-20 cm of soil and develop where the fertilizer is applied, fertilizer should always be given to the same area around each tree, except in the first years after planting:

- 1st year; at planting, in circle of radius 0.3 m around stem.

- 2nd year; in band 0.3-0.6 m around stem.

- subsequent years; either in band 0.6-1.0 m around stem or in 80 cm-wide strips between rows and between trees.

There is a computer programme at IRCC, Montpellier, with which to calculate recommended rates of application as below:

g P_2O_5/plant = 2.29 W (shortfall in soil below optimum level) / 1000

g K_2O/plant = 47.1 W (shortfall in soil below optimum level) / 100

g MgO/plant = 20.2 W (shortfall in soil below optimum level) / 100

g CaO/plant = 28.1 W (shortfall in soil below optimum level) / 100

where W = corrected soil weight per plant (crown or strips) = apparent soil density x surface area x depth of 0.2 m

The optimum levels of K, Mg and Ca as m.e. % in the soil are computed from base saturation and a ratio of 8 % : 68 % : 24 % in the total of exchangeable bases (for worked example, see A in Present fertilizer practices in specific regions).

Nitrogen is required when (m.e. % E.B. + 6.15)/N %o > 8.9, but the amount needed is based on the results of field experiments and not on soil analysis. If the ratio is < 8.9, no nitrogen fertilizer is required.

Preferred nutrient forms

Nitrogen: urea usually recommended unless S seems to be a limiting factor, in which case sulphate of ammonia would be preferred.

Phosphorus: rock phosphate advised when soil pH < 5.5, provided liming not needed; and superphosphate (triple unless Ca is low in exchangeable bases, when single is preferred) if soil pH >5.5.

Potassium: muriate (KCl)

Magnesium: kieserite, unless Ca also needed.

Calcium: lime (or dolomitic limestone if Mg also needed).

Present fertilizer practices in specific regions

Cote d'Ivoire, Cameroon and other countries applying soil diagnostic method.

Examples of calculations:

Soil analysis chart				
	Soil n° 1		**Soil n° 2**	
Carbon %	1.6		1.2	
Nitrogen %o	1.5		1.0	
Avail. P ppm	48		12 (Olsen modified)	
Exchangeable bases:		**% of total E.B.**		**% of total E.B.**
K m.e. %		0.50	2.7	0.12	4.8
Mg m.e. %		6.43	34.3	0.60	24.3
Ca m.e. %		11.83	63.0	1.75	70.9
Total E.B.		18.76		2.47	
				(Ammonium acetate extract)
Exchange capacity	19.30 m.e. %		5.60 m.e. %	
Base saturation	97 %		44 %	
pH (water)	6.1		5.2	

Apparent soil density may vary according to soil texture from 1 100 to 1 400 kg/m3. Assume 1 400 in this case. Soil depth is 0.2 m.

So, in 1st year, W = (area of circle of radius 0.3 m) x 0.2 x 1 400
= pi x 0.3^2 x 280
= 79 kg

And in 2nd year, W = (area of band between circles of radius 0.6 m and 0.3 m) x 0.2 x 1400
= pi x (0.6^2 - 0.3^2) x 280
= 238 kg

And in 3rd year, W = (area of band between circles of radius 1.0 m and 0.6 m) x 0.2 x 1400
= pi x (1.0^2 - 0.6^2) x 280
= 563 kg

On soil no.1, available P should be raised to 100 ppm.

K:Ca:Mg ratio should be 8 : 64 : 24 but, as saturation is high, complete correction is impossible, so only K will be applied to raise K to 8 %, i.e. to 1.6 m.e. %; even this will oversaturate the exchange capacity by 2 %.

For N, (m.e. % E.B. + 6.15)/N %o = (18.76 - 6.15)/1.5 = 16.6, so nitrogen fertilizer is needed.

Rates of application (g/plant):	**Year 1**	**Year 2**	**Year 3**
Triple super (100-48)2.29 W/1000/0.44 =	21	64	152
KCl (1.6-0.5)47.1 W/100/0.60 =	68	206	486
Urea	50	75	100
Sulphate of ammonia could be applied instead of urea and ammonium phosphate instead of triple superphosphate.			

For soil no.2, available P should also be raised to 100 ppm.

Base saturation should be raised to 60 % and the K:Ca:Mg ratio should be 8:68:24, so:

Total E.B. = 5.6 x 0.6 = 3.36 m.e. %.
K = 3.36 x 0.08 = 0.27 m.e. %.

Ca = 3.36 x 0.68 = 2.28 m.e. %.
Mg = 3.36 x 0.24 = 0.81 m.e. %.

And (m.e. % E.B. + 6.15)/N %o = (2.47 + 6.15)/1.0 = 8.6

Rates of application, calculated in the same manner as for soil no. 1, are then:

Rates of application (g/plant)	Year 1	Year 2	Year 3
Triple super	36	107	258
KCl	9	28	66
Lime = (2.28-1.75)28.1 W/100/0.67 =	17	53	125
Kieserite = (0.81-0.60)20.2 W/100/0.27 =	12	37	88

Dolomitic limestone could be applied instead of lime and kieserite.

No nitrogen fertilizer is needed.

Brazil

The decision whether to apply fertilizers depends on the quality of plantation management, shade intensity, soil depth and drainage. The soil is analysed to monitor requirements.

In the Amazon region, natural high-fertility soils do not need fertilizers for the first 5 years after planting.

Requirements for low-fertility soils are based on critical levels of nutrients, particularly P and K, in the soil, as shown below. In new forest clearings, soil sampling to assess Ca and Mg levels should be done before and after burning. A composite sample of 12 borings per hectare is recommended. Sampling should be repeated every 3 years.

Nutrients	Critical levels	Criteria for fertilizing		Nutrients kg/ha					
		P	K	Amazonia			Bahia		
				N	P2O5	K2O	N	P2O5	K2O
Phosphorus	Low (L) < 6 ppm	L	L	30	90	60	60	90	90
	Average (A) 7-15 ppm	L	A	30	90	30	60	90	45
	High (H) >15 ppm	L	H	-	-	-	60	90	-
		A	L	30	60	60	60	45	90
Potassium	Low (L) ≤0.12 m.e.%(47 ppm)	A	A	30	60	30	60	45	45
	Average (A) 0.13-0.30 me.%	A	H	-	-	-	60	45	-
	(47-117 ppm)	H	H*	15	15	10			
	High (H) >0.30 me.% (117 ppm)	H	H**	-	-	-			
		Ca+Mg	Al	Liming:					
Calcium + Magnesium	Low (L) Amazonia = <2.0 m.e.%	L	L	No liming					
	Bahia = <3.0 me.%	L	A/H	t/ha CaO = 1.5 x Al					
Aluminium	(A/H) Amazonia > 3.0 m.e.%	A/H	L	No liming					
	Bahia > 0.4 m.e.%	A/H	A/H	(Al x (Al % - 15 %))/Al % = t/ha CaO					
* Maintenance fertilizing when cocoa prices are favourable; ** Profiting from residual effects of fertilizers when prices are low.									
Available P ppm according to Bray & Kurtz no.2 Al = Al m.e.%; Al % = Aluminium saturation minus 15 % (15 % is the acceptable level)									

Fertilizer N use should be moderate and based on light intensity and on field observation of possible deficiency symptoms. Urea may suffer some loss by volatilization of ammonia, particularly in alkaline soils or in soils rich in fresh organic matter. Soluble forms of P (mono-

or di-ammonium phosphate, single or triple superphosphate) are preferred, except on acid soils where rock phosphate may be used. Liming is needed only in exceptional circumstances where exchangeable Al > 3 m.e. %.

No fertilizers are usually given in the nursery but 0.5 % urea spray may be applied to the leaves if N deficiency symptoms appear. The first application in the field is usually given 2-4 months after planting, in a circle of 0.5 m radius around the stem, in 2 dressings per year. In subsequent years a basal dressing is given at the beginning of the rains, and supplemental N as indicated by field observations. In the second year the radius of the circle is increased to 1.0 m and from the third to the fifth years to 1.5 m. In later years, a blanket application between 4 trees on 9 m2.

Malaysia

An integrated approach is advocated, taking into consideration such factors as leaf nutrient content, age of trees, cropping level, soil type, amount of shade, leaching losses and other agronomic factors (tree vigour, harvesting system, etc).

Needs for N vary, depending on rainfall and shade. More N appears to be needed for high yield and refoliation of lightly shaded cacao. P, as basal dressing and planting-hole appliction of rock phosphate, benefits establishment and growth of young plants. For mature cacao, P is continuously required for sustained high yield. The need for K appears to decline as the trees mature, probably associated with the reduced growth rates and recycling of leaf litter and pod husks. Mg requirements have not been fully established, but there are indications that balanced nutrition is essential for high yield. Ca is needed for early establishment and growth but its role in mature trees needs further clarification.

Fertilizer recommendations

Nursery - compound fertilizer 12:12:17:2 with micronutrients, or 15:15:6:4 (slow-release 10:10:5:2 has also been used with success)

Age of seedling (months)	Rate (g)
2-3	1.0
3-4	1.5
4-5	2.0
> 6	3.0

Pre-planting and planting hole - on low-fertility acid inland soils (ultisol and oxisol)

- pre-planting:
400-600 kg/ha rock phosphate, 880 kg/ha ground limestone, ploughed into top 15 cm soil.

- planting hole:
150-230 g/plant rock phosphate.

Young cacao (Malaysian peninsular):				
Months after planting	**g/tree**			
	N	**P2O5**	**K2O**	**MgO**
1 ½	4.5	4.5	1.8	1.2
3, 5 and 8	7.5	7.5	3	2
11	12	12	17	2
14 and 17	17.5	8	21	2.2
20 and 23	23	11	28	3
27, 31, 35	35	16	42	4.5

Mature cacao - (kg/ha/year)			
Nutrient	**Soil analysis***	**Leaf (%)**	Fertilizer rate
N		< 2.0 2.0-2.6 > 2.6	100-150 60- 80 -
P2O5	< 15 ppm > 15 ppm	< 0.2 > 0.2 > 0.2	90-150 30- 60 -
K2O	< 0.3 m.e.% > 0.3 m.e.%	< 2.0 > 2.0 > 2.0	120-180 80-100 -
* Available P by Bray and Kurtz no.2; exchangeable K in m.e.%.			
Source: Ling, 1989			

Wyrley-Birch (1987), reviewing trials in Sabah 1964-1977, concluded that P was needed on the soils studied; K was also important, but not N.

Where soil nutrients are low, the accelerated removal of Ca by N fertilizers needs to be rectified by liming, which also helps to correct pH; losses of Mg are also significant. Consideration should also be given to possible effects of major nutrient application on micronutrients.

Tentative recommendations for mature cacao in Sabah:

	kg/ha	
Urea	90-110	(more may be needed if shade sparse)
Superphosphate (40 % P2O5)	110-170	
Sulphate of potash	110-280	(less K needed if pod
or muriate of potash	90-225	husks remain and are evenly distributed)
Kieserite	110-170	
Ground agricultural limestone	170-225	

Micronutrients

Boron and zinc are the more commonly reported deficiencies.

Remedy
- for B:
20-30 kg/ha borax (11.3 % sol.B) or other B-containing substances applied to the soil in a ring around the tree. Or foliar spray (200-300 g/l Solubor, Polybor or boric acid) repeated 3-4 times per year. Note that there may be a danger of toxicity after several years.

- for Zn:
10-20 kg/ha ZnSO4 applied to the soil. Or foliar spray of 1 % zinc sulphate or zinc oxide repeated 2-3 times per year.

Further reading

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