Deriving fertiliser recommendations for cocoa: an offtake model approach

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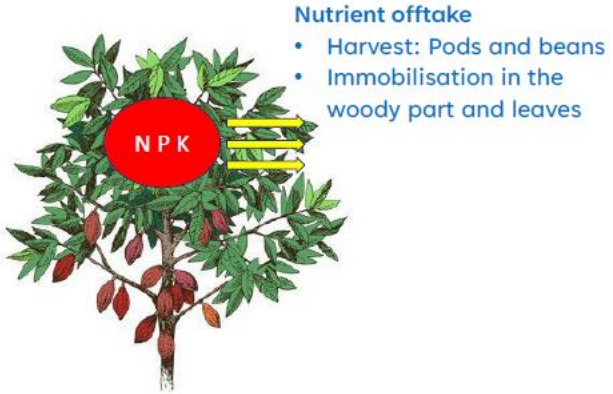
CocoaSoils

An offtake model approach

- **Why an offtake model?**
  - **Current fertiliser recommendations:** old, variability among countries and regions, lack of scientific rationale.
  - **Methods:** ambiguous interpretations, variability on sampling.
- **Aim:** To calculate the quantities of nutrients (N, P and K) required to replace those removed by the crop through the removal of pods and immobilisation in vegetative tissues.

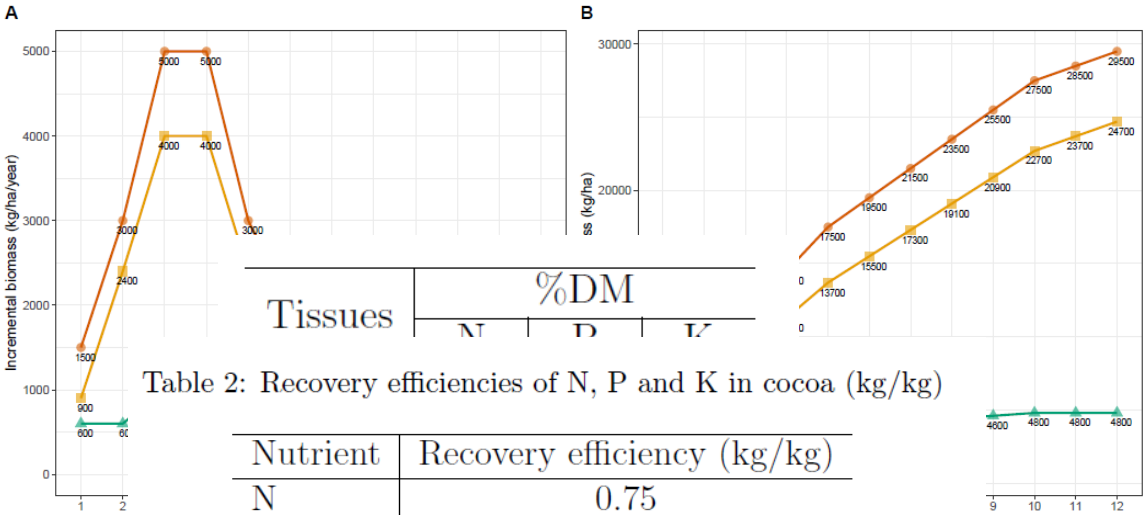


Assumptions

- Nutrient concentration in tissues is constant.
- Nutrients immobilised in the wood (i.e. no re-allocation takes place and the nutrient concentration in the wood is constant).
- Leaf biomass increases over the first 10 years.
- Nutrients in pod husk are removed from the field.
- Nutrient recovery efficiency is constant over time.
- The outcome of the model does not considered nutrients available from the soil or losses.

Parameters

- Tree age -> wood and leaf biomass increase
- Target
- Cocoa
- Nutrien
- Nutrien
- Other r



)05; Nijhof, 1987)

Tissues	%DM		
	N	P	K

Table 2: Recovery efficiencies of N, P and K in cocoa (kg/kg)

Nutrient	Recovery efficiency (kg/kg)
N	0.75
P	0.30
K	0.80

Calculation of nutrient offtake/immobilisation

Table 3: Calculation of nutrient offtake/immobilisation in beans, husks, wood and leaves

Offtake/immobilisation	Calculation (kg nutrient/ha/year)	Equation
Beans	yield × nutrient concentrations	1
Husks	((yield ÷ bean to pod ratio) − yield) × nutrient concentrations in husk	2
Wood	wood biomass increase × nutrient concentrations in wood	3
Leaves	leaves biomass increase × nutrient concentrations in leaves	4

- The sum of each offtake/immobilisation gives the total nutrient offtake expressed in kg ha-1 year-1 for N, P and K

Calculation of nutrient requirement

$$\text{Fertiliser Requirement (N,P,K)} = \frac{\text{Offtake (N,P,K)}}{\text{Recovery Efficiency (N,P,K)}}$$

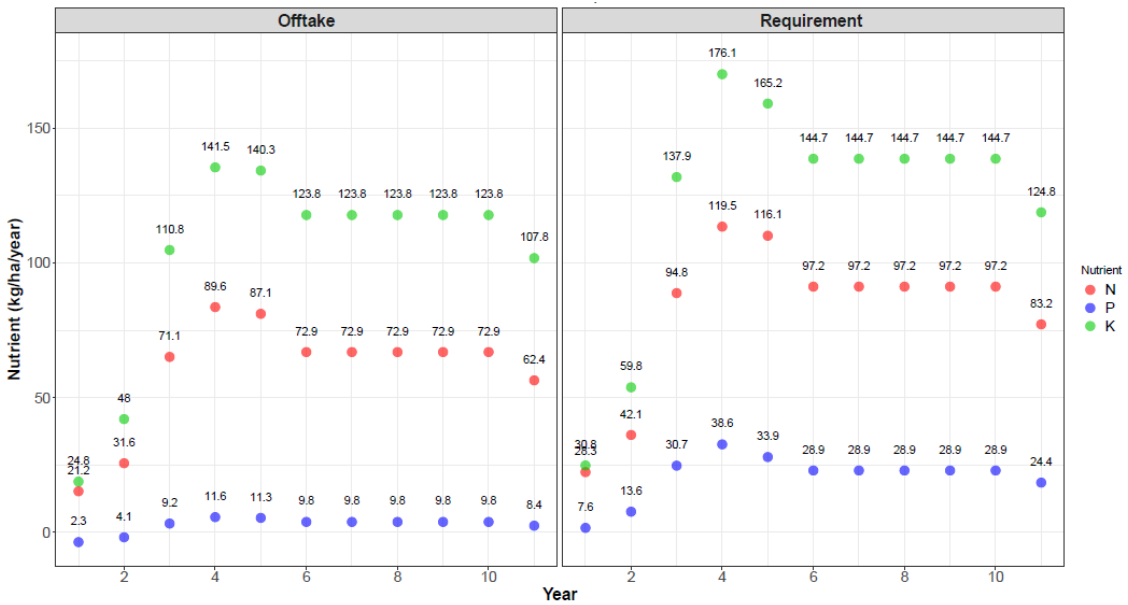
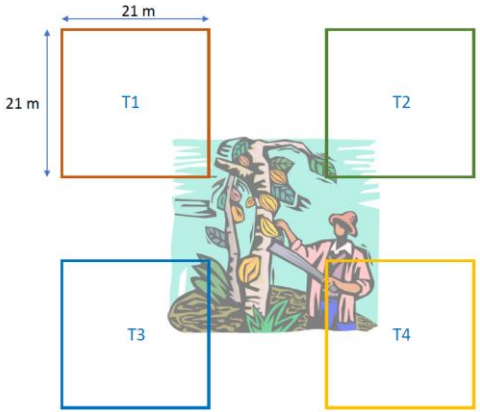


Figure 2: Nutrient offtake vs requirements using different target yields. Target yield: year 1,2 = 0, year 3 = 500 kg ha^{-1} yr^{-1}, year 4 = 1000 kg ha^{-1} yr^{-1}, and year 5 to 11 = 1500 kg ha^{-1} yr^{-1}.

Modified rates of P for high cocoa yields

For each additional 1 ton of dry beans ha^{-1} yr^{-1}, an additional 8 kg of P ha^{-1} yr^{-1} is added.

Model application: Satellite trials



T1: Current farmer practice + insecticide applications **(C+ I)**

T2: Weeding + pruning + insecticide applications + fungicide applications, no fertilizer **(BMP + no F)**

T3: Weeding + pruning + insecticide applications + fungicide applications + current national fertilizer recommendations **(BMP + NF)**

T4: Weeding + pruning + insecticide applications + fungicide applications + improved fertilizer recommendation based on offtake model **(BMP + OF)**

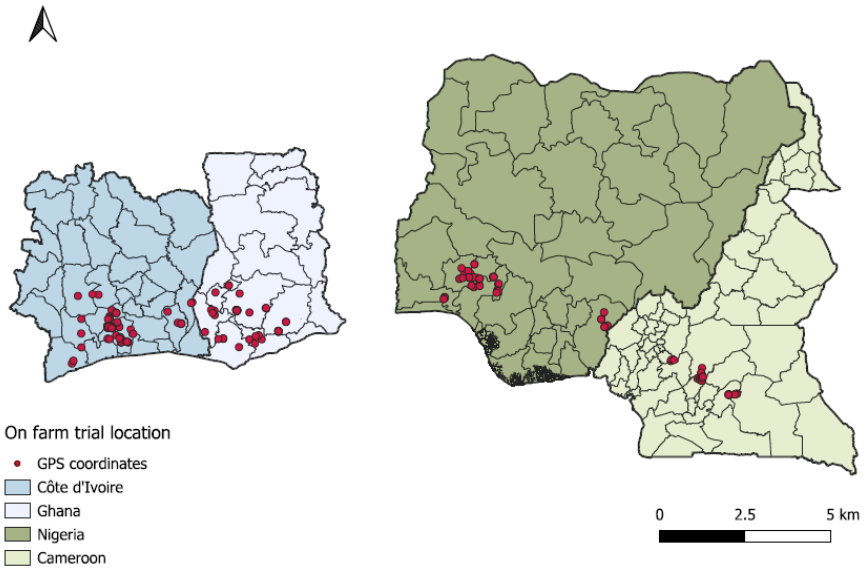


Figure 3: Location of on-farm trials (n = 195) used for yield evaluation across West Africa: Côte d'Ivoire (72), Ghana (41), Nigeria (50) and Cameroon (32).

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National fertilizer recommendations vs offtake model

Table 4: Summary of national fertiliser recommendation and fertiliser rates based on the offtake model, assuming dry bean of 1000 kg ha^{-1} yr^{-1} and a tree age of 11-22 years.

Country	Region	Rate T3 (kg ha^{-1} yr^{-1})			Rate T4 (kg ha^{-1} yr^{-1})			Period
		N	P	K	N	P	K	
Cameroon	all	0	23	35	29	10	48	May-Jun
		0	0	0	29	10	48	Jul-Aug
	Total	0	23	35	58	20	96	
Côte d'Ivoire	East & Center	0	17	26	29	10	48	May-Jun
		0	0	0	29	10	48	Aug-Sept
	Total	0	17	26	58	20	96	
	West	0	22	35	29	10	48	May-Jun
		0	22	35	29	10	48	Aug-Sept
	Total	0	44	70	58	20	96	
Ghana	all	0	36	56	29	10	48	April-May
		0	0	0	29	10	48	Aug-Sept
	Total	0	36	56	58	20	96	
Nigeria	all	25	11	21	29	10	48	April-May
		25	11	21	29	10	48	Aug-Sept
	Total	50	22	41	58	20	96	

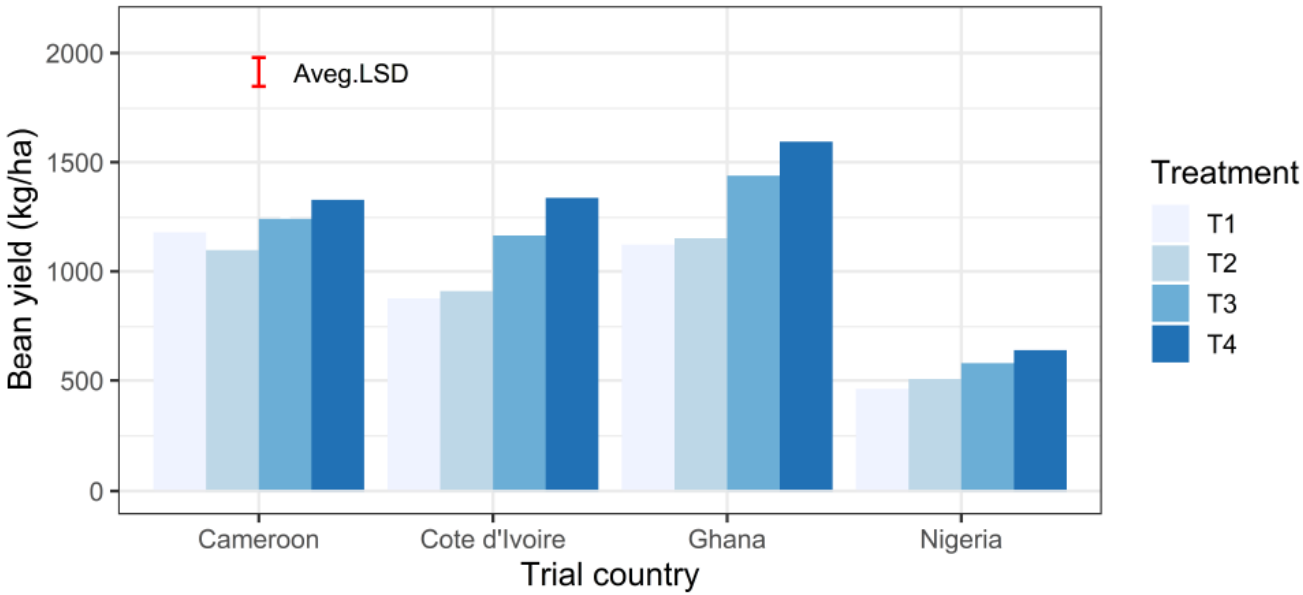
Yield assessment

$$\text{yield} \sim (\text{trial country} + \text{shade tree density} + \text{cocoa tree density} + \text{plantation age}) \times \text{treatment} + (1|\text{administrative division/trial\_id})$$

Treatment	*Mean*	*SE*	*DF*	*LL(95%)*	*UL(95%)*	LetterGrp
T1	912	114	33.8	681	1144	A
T2	917	114	33.8	686	1149	A
T3	1109	114	33.8	878	1341	B
T4	1227	114	33.8	995	1458	C

Letter-based representation of pairwise comparisons at significant level '0.05'

Yield assessment



A positive overall yield effect of T4 over T3; however, the difference was significant only in Cote d'Ivoire.

Predicted bean yield in Cameroon, Cote d'Ivoire, Ghana and Nigeria by Treatment. The average LSD (Aveg.LSD) bar indicates significant differences among treatments within countries.

Economic assessment

Table 8: Gross and net return, value-cost ratio (VCR) and benefit-cost ratio (BCR) determined for yield increases in T3 and T4 based on yield estimates in 2021/2022, farm gate cocoa prices and cost of fertilisers in 2020/2021 and 2022/2023.

Treatment	Country	Yield	Yield increase[a]	Farmgate price[b] (US$/kg)		Cost of fertilisers[c] (US$/ha)		Gross return (US$/ha)		Net return (US$/ha)		VCR		BCR	
		(kg/ha)	(kg/ha)	20/21	22/23	20/21	22/23	20/21	22/23	20/21	22/23	20/21	22/23	20/21	22/23
T3	Cameroon	1244	148	2.8	2.6	412.9	378.9	217.0	424.0	196.0	-45.1	1.9	0.9	0.9	-0.1
T4	Cameroon	1330	234	2.8	2.6	652.9	599.0	358.4	723.4	294.4	-124.4	1.8	0.8	0.8	-0.2
T3	Nigeria	585	78	2.5	2.8	192.7	215.3	200.0	320.0	-7.3	-104.7	1.0	0.7	0	-0.3
T4	Nigeria	644	137	2.5	2.8	338.4	378.1	183.1	281.6	155.3	96.5	1.8	1.3	0.8	0.3
T3	Ghana	1439	283	1.8	1.4	509.4	390.5	107.9	523.8	401.5	-133.3	4.7	0.7	3.7	-0.3
T4	Ghana	1593	437	1.8	1.4	786.6	603.1	246.7	1220.9	539.9	-617.9	3.2	0.5	2.2	-0.5
T3	Côte d'Ivoire	1169	259	1.7	1.4	440.3	373.0	71.7	101.7	368.6	271.3	6.1	3.7	5.1	2.7
T4	Côte d'Ivoire	1339	429	1.7	1.4	729.3	617.8	229.0	326.2	500.3	291.5	3.2	1.9	2.2	0.9

[a]Control yields from T2 were used to calculate yield increases: Cameroon = 1096, Nigeria = 507, Ghana = 1156, Côte d'Ivoire = 910.

[b]Farm gate prices in Nigeria are averaged based on a minimum a maximum estimate (20/21: 1.56 – 3.38 US$; 22/23: 1.92 – 3.6) due to a high variability among farmers. In Cameroon, Ghana and Côte d'Ivoire prices are regulated by the government and the cocoa board.

[c]Fertiliser prices are obtained based on fertiliser purchase records paid by the CocoaSoils project in the application year.

The large differences in profitability among countries and treatments follow the differences in yields among countries and the high cost of fertiliser.

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Points to improve in the offtake model

- Biomass accumulation: include different growing scenarios (planting density, shade level, management practices, etc.)
- Nutrient concentration in tree components: include tree dynamics (age, management)
- Nutrient recovery efficiency: short and long-term nutrient efficiency in cocoa.
- Available soil pools, and nutrient losses.

Conclusions

- Fertiliser application positively impacts cocoa yield; however, responses are still poorly understood.
- An offtake model approach could provide a more accurate approximation of cocoa's nutrient needs .
- Achieving higher yields will not depend only on improving fertilizer recommendations.
- Fluctuating net returns in the face of varying and low cocoa prices and increased fertiliser costs have a great impact on profitability.
- Low capacity to invest in fertiliser while cocoa farm gate prices remain low.

Acknowledgments

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- Farmers

Thank you!

Questions?