Cocoa Yield under Good Agricultural Practices and 4R Nutrient Management in Indonesian Smallholder Systems

By Thomas Oberthür, Marianne Samson, Noel Janetski, and Kate Janetski

Researchers combined a suite of good agricultural practices with 4R-consistent nutrition to achieve a rapid improvement in cocoa bean yield and quality under the guidance of local Cocoa Carers and Monitors. Close monitoring of the soil nutrient balances will be required to sustain this early gain.

KEYWORDS:
sustainable intensification; cocoa fertilization; dry bean yield; bean size; good agricultural practices

ABBREVIATIONS AND NOTES:
N = nitrogen; P = phosphorus; K = potassium; Mg = magnesium; S = sulfur; Ca = calcium; OM = organic matter; ROI = return on investment.

IPNI Project IDN-27

https://doi.org/10.24047/BC10213

Cocoa global production has surged strongly over the past 20 years to nearly 4.6 million (M) t, mostly from West Africa (FAO, 2013, 2016). Between 2020 and 2025, consumers' demand for cocoa will increase by 1 M t (ICCO, 2015), mainly driven by the growing consumption in the Asia-Pacific region, particularly China and India (Squicciarini and Swinnen, 2016). Growth in West African production has stagnated over the last 10 years at a level of about 2.7 M t, and continued growth in demand has encouraged new producers into the market. Indonesia is now the world's third largest producer, with a planted area between 0.8 to 1.1 M ha, seemingly well placed to benefit from global market developments.

Until recently, growth of production has been almost entirely through expansion of area. With the exception of Central America, which has shown a steady improvement over the past 20 years, yield in many areas has plateaued at an average close to 0.5 t/ha (Baah et al., 2011; Assiri and Koko, 2009), well below a theoretical potential of 11 t/ha (Corley, 1983). Indonesia is no exception, and since 2010 yield has dipped below 0.5 t/ha, undermining cocoa farm profitability and presenting substantial risks to the survival of the industry in Indonesia. At the same time, global markets are strong. The opportunity for Indonesia is to benefit from growth in global demand by pushing yield consistently beyond 1 t/ha. With adequate management in place, cocoa dry bean yields between 1 and 3 t/ha can be achieved in commercial fields (Ahenkorah, 1997; Butler, 2004; Maharaj et al., 2005; Pang, 2006, Koko et al., 2013). The role of adequate crop nutrition as part of adequate agronomic management for high cocoa yields has long been known (Cunningham and Arnold, 1962). Application of fertilizer increased yields from a low 0.25 to 1.5 t/ha after four years (Ghana Cocoa Board, 2002). Trials in Colombia have shown average dry bean yields over five years exceeding 1 t/ha with balanced fertilization (Uribe et al., 2001).

On the other hand, the use of fertilizer in Southeast Asian smallholder cocoa systems is not common, and widespread nutrient deficiencies are prevalent (Nelson et al., 2010). Unfortunately, most nutrition knowledge has been developed for West Africa and Malaysia under conditions not representative of Indonesian production regions. Furthermore, farmers often view fertilizer use as risky because of uncontrollable effects of weather and disease, and there remains substantial uncertainty amongst farmers. An essential part of a change process would be knowledge that increases farmers' certainty as they manage fertilizer. The knowledge base must be locally specific, trusted by farmers to reflect what is happening on the ground, and relevant to the needs of small-scale operations and their suppliers. Farmers need support if we expect them to fertilize for rapid yield gains. This project illustrates how good agricultural practices consistent with 4R Nutrient Stewardship (IPNI, 2012) can impact cocoa bean yields and quality. The project demonstrates how such knowledge is developed in an on-farm setting that is conducive to increasing certainty amongst farmers about the effects of changed management, and enables the generation of credible knowledge on cocoa crop nutrition.

On-Farm Experiments

Twenty-two farms in Soppeng, South Sulawesi, Indonesia, ranging from 0.3 to 1.65 ha, were selected in similar environmental conditions, with trees of 3 to 5 years of age. Tree density and their individual location were mapped, and replanting done where trees were missing or unproductive. Cocoa grew typically under the leguminous tree species *Gliricidia sepium* providing on average 30% shade cover. All farmers received training in good agricultural practices (GAP) at the Mars Cocoa Academy. Farms were divided in two equal-sized parts. In one half, GAPS without additional fertilizer nutrients were implemented, while the other half received GAP with 4R-consistent nutrient management (GAPN). Good agricultural practices involve regular pruning, weeding, and phyto-sanitation (i.e., diseased pods are removed and pest and disease are controlled). In 4R Nutrient Stewardship, the right source of fertilizer is used, at the right rate, the right time, and in the right place. Our fertilizer recommendation was developed based on the replacement of exported nutrients by a target yield of 2 t/ha. Inorganic fertilizer nutrients were selected, because compost was limited. They were applied twice a year with the onset of the rainy season (Dec./Jan., July/Aug.). Nutrients were buried in four, 20-cm deep holes with 10 cm diameter, equally spaced around the tree, along the edge of the canopy to match root growth. In each treatment, 50 trees were monitored from June 2013 to June 2015. Trees were harvested bi-weekly to determine dry bean yield per tree and bean size as the number of beans in a 100-g sample. "Cocoa Carers", (i.e., highly trained farmers), conducted the monitoring and data were captured in a portable tablet and sent to Cocoa Care. Cocoa Carers and associated Cocoa Monitors, (i.e., extension agents with an academic background), employed by Cocoa Care, routinely met with farmers to discuss the progress of the on-farm experiments. Such discussions usually included neighboring farmers and were conducive to group learning and socializing the experimental process with farmers not included in the core group. Baseline soil samples were taken in June 2013, with subsequent sampling in June 2014 and December 2015. Leaf samples for nutrient tissue content analyses were taken in June 2013, and then in December 2013, June 2014, December 2014, and December 2015. All samples were analyzed by P.T. London Sumatra.

Production System Improvements

Table 1 lists the amounts for nutrients applied in the GAPN treatment. Assuming 1,100 trees/ha, they amounted to 160 kg N, between 30 and 60 kg P, 90 to 165 kg of K, 11 to 17 kg Mg, and 70 to 110 kg Ca applied per year. More P was applied in year 1 to account for the low P status. The application of K was gradually increased to avoid economic burden.

Today, cocoa yield in smallholder cocoa production systems of Sulawesi rarely exceeds 0.4 t/ha. With GAP, yields increased to almost 0.6 t/ha in the first year of engagement, and to 0.8 t/ha in the second year (**Table 2**). Combining GAP with 4R-consistent nutrition further increased yields to 0.8 t/ha and over 1.1 t/ha in years 1 and 2, respectively. These are average yields for the group. Top-performing farmers exceeded 1 t/ha during the first year, and the 2 t/ha barrier

Table 1. Nutrients applied per tree in the treatment including good agricultural practices and fertilizer nutrients (GAPN) over a period of two years.

	--------- Nutrients applied, g/tree ---------					
	N	P	K	Mg	S	Ca
July 2013	99	23	44	-	35	-
January 2014	45	33	37	15	30	236
Subtotal Year 1	144	56	81	15	65	236
July 2014	74	13	75	5	54	-
January 2015	74	13	75	5	54	-
Subtotal Year 2	148	26	150	10	108	0
Total	292	82	231	25	173	236

Notes: 22 farms. Fertilizers included an NPK compound source (15-15-15), urea, ammonium sulphate, potassium chloride, dolomite, and rock phosphate.


Growers sorting their harvested cocoa pods.


A look inside an open pod.


Indonesia is now the world's third largest producer of cocoa and strong market demands present an opportunity for Indonesia's smallholders, which can be met by lifting yields beyond traditional thresholds with 4R-consistent nutrient management. Cocoa Care & T. Oberthür/IPNI Images

ENHANCED ARTICLE
Watch Our Video!

TAKE IT TO THE FIELD

Yields above 1,000 kg/ha were common for fertilized farms throughout most of the study and this progress instilled confidence amongst cocoa growers about their investment in fertilizer. Improving agronomic skills is a critical part of shielding this vulnerable group against a loss in their investment, which typically takes place during periods of adverse market or weather conditions.

in year 2. One farmer came close to 3 t/ha in the second year of management change.

Quality of beans is a criterion for sales transactions. Large beans have less shell, hence waste, and typically higher fat content, which may attract price premiums. We used bean count as proxy for size. The industry considers bean counts lower than 100 as very good, and counts above 120 are outside commercial standards. Farms participating in the Cocoa Care/IPNI program recorded bean counts far below 100, with year 2 better than year 1, and GAPN significantly improving on GAP (**Table 2**).

Table 2. The effects of good agricultural practices without fertilizer nutrients (GAP), and GAP including fertilizer nutrients (GAPN) on dry bean yield (t/ha) and bean size of cocoa (as number of beans per sample of 100 g) over a period of two years.

	Dry bean yield, t/ha		Bean size, Number/100 g	
Treatment	Year 1	Year 2	Year 1	Year 2
GAP	0.582	0.790	93.6	73.4
GAPN	0.791	1.169	90.2	69.5
Significance at 5%	***	****	****	****

Notes: 22 farms. Yield was converted to a per ha basis using a tree density of 1,100 trees/ha.

Traditionally, most cocoa in Sulawesi is harvested between June and August. Cash income is restricted to these months, and curtails significantly farmers' ability to invest in farm inputs required during other times of the year. Good agricultural practices induced production in months during which little crop is normally harvested, and adding nutrients further improved the distribution of marketable cocoa beans (**Figure 1**). The typically low period between January and June was remarkably productive. Year 2 data indicate that adding nutrients successively increased the yield gap over good agricultural practices only.

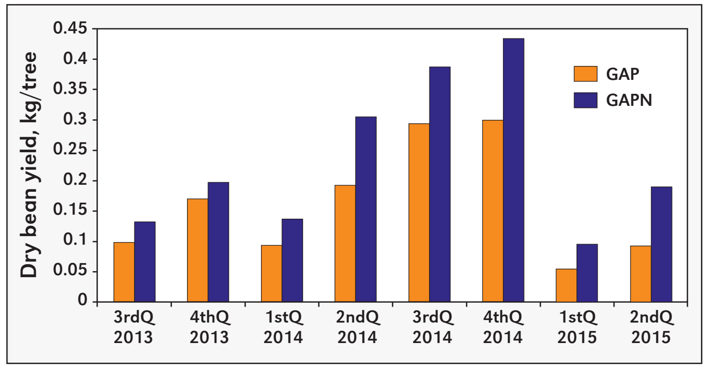

Figure 1. The effects of good agricultural practices without fertilizer nutrients (GAP), and GAP including fertilizer nutrients (GAPN) on dry bean yield distribution over eight quarterly measurement periods. Average values of yield from 22 farms.

Tables 3 and **4** present the results from the laboratory analyses of soil and tissues samples, respectively. Both GAP and GAPN improved soil pH to an optimal point for cocoa. Soil organic matter dropped somewhat in Year 1, but increased again in Year 2 under both management options. This is likely an effect of regular pruning in all farms. Total soil N remained stable, except for an increase in GAPN in Year 2, which was expected given the optimal supply of external fertilizer N. Soil P and K was considered somewhat low at the start of the program, and fertilizer inputs were designed to increase concentrations, and then maintain them. Decreased exchangeable Mg in Year 2 in both treatments signal that the reduction of fertilizer Mg in that year was an incorrect decision. Year 2 values indicate that high yields under GAPN may have started excessive soil Mg removal that needs correction in the coming years. Higher yields under both treatments will have extracted more Mg than was replaced by fertilizer applications. Calcium was initially high and were acceptable after Year 2. Adequate nutrient management is required to maintain the Ca concentration to ensure that cation balances remain at present ratios to prevent

Table 3. Soil properties at baseline sampling before treatment implementation in June 2013, and as affected by good agricultural practices without fertilizer nutrients (GAP), and GAP including fertilizer nutrients (GAPN) determined in 2014 and 2015.

	pH	OM	Total N	Bray P	Exch. K	Exch. Mg	Exch. Ca	Ca:Mg ratio	(Ca+Mg):K ratio
		- - - - - % - - - - -		mg/kg	- - - - - - meq/100 g - - - - - -				
Base 06/2013	5.4	4.4	0.19	40.5	0.68	5.5	26.6	6.8	50.6
GAP 06/2014	7.0	4.0	0.18	43.6 a	0.54	4.3	20.3	5.7	52.5
GAPN 06/2014	7.0	3.9	0.19	28.6 b	0.56	4.8	18.9	4.8	50.3
GAP 12/2015	6.9	4.4	0.18 b	59.0	0.90	3.1 a	15.8	5.2	27.8
GAPN 12/2015	6.8	4.3	0.30 a	78.6	0.69	2.9 b	16.1	5.6	28.4

Notes: June 2013/2014, 22 farms; December 2015, 12 farms; others had applied fertilizer in GAP. Differences within each year between GAP and GAPN were tested for statistical significance. Values without letters are not significantly different from one another within the same year at $p < 0.05$.

Table 4. Measured concentration of nutrients in leaf tissue, as affected by good agricultural practices without fertilizer nutrients (GAP), and GAP including fertilizer nutrients (GAPN), at four different sampling dates.

	GAPN	GAP	Difference	Significance[1]
		N concentration, %		
December 2013	1.856	1.689	0.171	**
June 2014	1.935	1.916	0.019	ns
December 2014	1.714	1.779	-0.065	ns
December 2015	1.818	1.874	-0.057	ns
		P concentration, %		
December 2013	0.136	0.149	-0.012	**
June 2014	0.140	0.141	-0.001	ns
December 2014	0.127	0.126	0.001	ns
December 2015	0.113	0.108	0.005	ns
		K concentration, %		
December 2013	1.621	1.644	-0.024	ns
June 2014	0.747	0.738	0.010	ns
December 2014	1.596	1.514	0.082	ns
December 2015	1.482	1.548	-0.066	ns
		Mg concentration, %		
December 2013	0.563	0.545	0.018	ns
June 2014	0.215	0.226	-0.011	ns
December 2014	0.447	0.439	0.008	ns
December 2015	0.298	0.258	0.039	ns
		Ca concentration, %		
December 2013	2.436	2.402	0.035	ns
June 2014	1.716	1.748	-0.032	ns
December 2014	2.131	2.098	0.033	ns
December 2015	1.220	1.033	0.188	ns

Notes: 22 farms sampled at all dates. [1] ** = significance difference at $p < 0.05$; ns = not significant.

antagonistic uptake effects on K and Mg by Ca.

For the last two sampling dates, leaf tissue concentrations of P, Mg, and Ca were higher in GAPN, and somewhat lower for N and K, compared to GAP. With both management options, a common trend is observed for all monitored nutrients—tissue concentration was highest at the initial sampling dates.

This trend confirms the indications from the soil analyses that higher yields under both management options are removing more nutrients than the soil and fertilizer can currently supply. Nutrient supply in the coming years, from inorganic and organic sources, will have to arrest the downward trend to prevent soil nutrient mining. Given the success of the Cocoa Care extension with Carers, Monitors, and the strong markets, farmers increasingly embrace sustainable intensification, of which responsible use of soil resources is an accepted component. The timely establishment of adequate nutrient supply chains has become critical.

Conclusions

Intensified cocoa smallholder production systems have been established under an extension approach led and driven by highly trained farmers, guided by Cocoa Care. The impact of 4R-consistent nutrient management as part of this approach has been demonstrated with an on-farm trial network. Peer learning between farmers, coupled to strong markets for quality cocoa, is leading to a rapid adoption of improved, intensive management. The fertilizer industry needs to engage in a timely manner with the cocoa sector to ensure accessible and affordable nutrient supply chains prevent soil resource depletion under intensive cocoa production systems. **BC**

Dr. Oberthür (e-mail: toberthur@ipni.net) and Ms. Samson are with IPNI Southeast Asia, Penang, Malaysia. Mr. and Ms. Janetski are with Community Solutions International's Cocoa Care Program, Bali, Indonesia.

References

Ahenkorah, Y. 1997. In Proc. Soil Science. Ghana 14 & 15:21-29.
Assiri, A.A. and K.L. Koko. 2009. 16th International Cocoa Research Conf., Bali, Indonésie.
Baah, F. et al. 2011. Agric. Biol. J. N. Am. 2:173-181.
Butler, D.R. et al. 2004. In Proc. APASTT Seminar—Exhibition, Re-vitalisation of the Trinidad & Tobago Cocoa Industry, pp.39-48 St. Augustine, Trinidad.
Corley, R.H.V. 1983. Experimental Agriculture 19:217-237.
Cunningham, R.K. and P.W. Arnold. 1962. J. Sci. Food Agric. 13:213-221.
FAO Statistics Division. 2013. Viale del Terme di Caracalla, Rome, Italy.
FAO Statistics Division. 2016. Viale del Terme di Caracalla, Rome, Italy.
Ghana Cocoa Board. 2002. Report of the Committee on Application of 'High Technology' Method on Cocoa Production in Ghana. Accra: Ghana Cocoa Board.
ICCO. 2015. Westgate house, Ealing, London, UK.
IPNI. 2012. 4R Plant Nutrition Manual: A manual for improving the management of plant nutrition. (T.W. Bruulsema et al. eds.) IPNI, Norcross, GA, USA.
Koko, L.K. et al. 2013. Agroforest Syst. 87:1043-1052.
Pang, J. T. Y. 2006. Expl. Agric. 42:289–299.
Maharaj, K. et al. 2003. In Proc. International Workshop on Cocoa Breeding for Improved Production Systems (F. Bekele et al. eds.) Accra, Ghana, pp.171-182.
Nelson, P.N. et al. 2010. 19th World Congress of Soil Science, Soil Solutions for a Changing World. 1-6 Aug. 2010, Brisbane, Australia.
Squicciarini, M.P. and J. Swinnen, 2016. *In* The Economics of Chocolate (M.P. Squicciarini and J. Swinnen eds.). Oxford Univ. Press, pp.1-10.
Uribe, A. et al. 2001. Better Crops International. 15(2):3-5.