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Mapping Cocoa Productivity in Ghana, Indonesia and Côte d'Ivoire

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Abstract

In order to obtain an understanding of farm practices and drivers of on-farm cocoa yields, a survey and a programme of regular crop monitoring was conducted across a range of farms in the top three cocoa-producing countries: Côte d'Ivoire, Ghana and Indonesia. For each country, groups of farms were sampled from key cocoa-growing regions or provinces and their physical characteristics were mapped (120 farms in Indonesia, 96 in Ghana and 48 in Côte d'Ivoire). Farm practices were determined by a farmer interview and crop development on selected trees from each farm was observed every six weeks over a period of four years in Ghana, three years in Indonesia and one year in Côte d'Ivoire.

Farms in Ghana and Côte d'Ivoire were older and larger than those in Indonesia. In all three countries, planting density varied considerably (276 to 3626 trees ha^{-1} in Ghana, 556 to 1848 trees ha^{-1} in Côte d'Ivoire and 272 to 2598 trees ha^{-1} in Indonesia) and often deviated from recommendations. Trees on all of the farms in Ghana and Côte d'Ivoire were seed derived, whilst a mixture of seed-derived and clonal material was cultivated in Indonesia. A larger proportion of farms (96%) were owner-operated in Indonesia compared with Côte d'Ivoire and Ghana (58% and 69%, respectively). Soil analyses in Ghana and Indonesia showed that nutrient levels were below threshold levels on many farms, illustrating the need for fertiliser applications to be matched to local conditions.

Considerable farm-to-farm variation in yield was recorded for each country. For example, in Ghana 30 and 10-fold differences in yield were observed between farms for the years 2012/13 and 2013/14, respectively. Geographical variation in yield was much greater in Indonesia, where cocoa cultivation is spread over a larger area than in Ghana and Côte d'Ivoire. Farm to farm variation within each country was partially explained by a number of common factors. These included planting density (many farms were planted below recommendations), whether or not the farmers fertilise their farms and whether or not they sprayed fungicides. In Ghana, insufficient soil phosphorus was another factor underlying yield variation between farms.

Overall, the results of this study demonstrated the potential for yield improvement on existing cocoa farms, without significant expansion of the area cultivated, through husbandry practices (such as gap-filling/ replanting of low density farms), targeted fertiliser application and carefully timed pest and disease control.

Introduction

Average yields on cocoa farms worldwide remain low. For example, according to FAO (2016) average annual cocoa yields varied between 395 and 550 kg ha^{-1} and 400-511 kg ha^{-1} in Ghana and Indonesia respectively over the period 2010 to 2013. Nevertheless, significantly higher yields have been reported under both experimental and field conditions (e.g. Edwin and Masters, 2005; Ahenkorah *et al*., 1974). The implication therefore is that there is considerable potential for improvements in on-farm yields.

If the predicted increase in demand for cocoa beans is to be met then it is important that this should be achieved through increases in productivity on existing cocoa farms through sustainable intensification of agricultural practice. This will provide an improved income to smallholder farmers as well as relieving land pressure. Extension activities geared towards yield improvement can be better focussed if background information is available on the current condition of cocoa farms, the practices in place and the amount of yield variation present. With this in mind, an extensive survey was conducted in the three largest cocoa-producing countries; Côte d'Ivoire, Ghana and Indonesia. The specific aims of the project across the three countries studied were:-

- To quantify the variability in the physical characteristics of smallholder cocoa farms (in terms of size, planting density, shade trees present and soil parameters)

- To assess farming practices in place and challenges faced by farmers
- To assess the extent of yield variation between farms and to gain a better understanding of factors underlying this variation.

Methods

Farm selection

In Ghana, ninety-six farms were selected from the four main cocoa-cultivating regions: Western, Brong Ahafo, Ashanti and Eastern Regions (24 farms per region) during April to August 2012. Selection of farms was purposeful to ensure that a range of farming practices were included in the survey. To achieve this, farms were selected that were either signed up, or not, to particular intervention schemes (where farmers receive advice on good agricultural practice). In Indonesia, a total of 120 farms were selected during March-April 2014 from eight provinces: Western Sumatra, Lampung, West Sulawesi, Central Sulawesi, South-East Sulawesi, South Sulawesi, East Java and West Papua. The criterion for farm selection was that there should be five farms in each province for which the management was considered “intensive”, five for which the management was considered “semi intensive” and five for which the management was classified as “not intensive”. For Côte d’Ivoire, forty-eight farms were selected across four geographical areas in December 2015: Abengourou-Kotobi, Gagnoa-Divo, Soubré and Guiglo.

Baseline data and farmer surveys

In each country baselines parameters were collected from each farm, which included the farm size (measured using a GPS device), cocoa tree density and shade trees present. Soil samples were collected from each farm and analysed for key macronutrients. Farmers were interviewed using a standardised questionnaire in order to obtain information on farm practices in place on each farm. The questionnaire included background information on the farmers (including their age, level of education etc.); characteristics of the farms including the ownership status of the farm; agronomic practices in place; where farmers obtained information and other support for their farming activities from. *Productivity assessments*

In each country a standardised procedure was adopted to assess farm-to-farm yield variation. Sixteen trees were labelled on each farm and data were collected on a six-weekly cycle. In Ghana data were collected from 2012-2016, in Indonesia from 2014 to 2017 and in Côte d’Ivoire during 2016.

Flower number, flushing percentage and number of pods in each of the following categories: “tiny”, “small”, “medium”, “large” and “ripe” on each tree were recorded. The number of pods infected with *Phytophthora* pod rot was also recorded as was the number of pods with mirid infestations. To assess the number of pods harvested between two treks, t_1 and t_2, the following formula was used:-

Number of pods harvested at t_2 =

$\sum$ (number of large and ripe pods at t_1) – number of pods that have progressed from large to ripe

An assumption was made that, between two time points, all ripe pods would have been harvested, whereas a large pod may either progress to the ripe category or else may go all the way to harvest. The number of pods per hectare was then calculated by multiplying the number of pods per tree by the planting density (trees per hectare). Values were then converted to dry beans ha^{-1} using pod value measurements calculated from farm samples.

A multiple regression approach, using the backward stepwise variable selection method of Draper and Smith (1998), was employed to explain yield variation between farms. The parameters initially incorporated into the model included cocoa tree density, soil parameters, variety cultivated and agricultural practices (as determined by the questionnaire). Prior to model fitting, all continuous variables were tested for normality using the Shapiro-Wilk test and data were transformed where appropriate. The model was fitted using the Generalised Linear Regression model in Genstat 17th Edition with the output including Wald tests for dropping terms. After the first run of the model, the term in the Wald tests output with the lowest t-test value was dropped and the model fitting repeated. This iterative process was repeated until all the remaining terms in the Wald test were significant at 5%.

Results

Farmer characteristics

Characteristics of the farmers in Ghana, Côte d’Ivoire and Indonesia are summarised in Table 1. A significant gender imbalance was noted in each country in that the majority of farmers were male. This was particularly marked in Côte d’Ivoire where 98% of the farmers in the survey were male. Overall, the farmers were older in Ghana compared with Côte d’Ivoire and Indonesia. In Ghana, 52% of the farmers were over 50, compared with 29% in Côte d’Ivoire and 38% in Indonesia. The proportion of farms that were owner-operated was greater in Côte d’Ivoire than in Ghana and in Indonesia most of the farms (96%) were owner-operated.

Table 1. Summary of the characteristics of farmers in Ghana, Côte d'Ivoire and Indonesia.

Characteristic	**Ghana**	**Côte d'Ivoire**	**Indonesia**
Gender balance (male: female)	83.5:16.5	98:2	87.5:12.5
Farmer age: proportion over 50 years old	52%	29%	38%
Proportion of farmers owner-operated	58%	69%	96%

Farm characteristics

On average, farms were smaller in Indonesia compared with Ghana and Côte d'Ivoire, and in all countries the distribution was skewed with a small number of larger farms. The mean and (and median) farm sizes were 0.71ha (0.63ha), 2.17ha (1.55ha) and 2.80ha (2.21ha) in Indonesia, Ghana and Côte d'Ivoire, respectively. The smaller farm size in Indonesia implies a need for the farmers to maximise the output from their farm both from cocoa crops and from intercrops. A wide spread of farm ages was observed in each country although the oldest farms were found in Côte d'Ivoire and Ghana (Table 2). The regular planting of cocoa in distinct rows was much more prevalent in Indonesia than in Ghana and was not encountered at all on any of the farms sampled in Côte d'Ivoire. In all three countries, there was a considerable range of planting densities adopted, although, on average, densities were lower in Indonesia reflecting the greater use of intercropping. Generally intercropping arrangements were more structured on the farms in Indonesia compared with Ghana and Côte d'Ivoire with the second crop (such as coconuts) grown in evenly spaced rows. Another key difference between the countries was the use of clonal cocoa on some of the farms in Indonesia. These took the form of trees that had been top-grafted in the nursery before planting out into the field or else old trees that had been grafted on to (after which the crown of the original trees is cut down). Regarding the source of planting material, only 8.4% and 45% of farmers in Côte d'Ivoire and Ghana, respectively, obtained seed from recommended seed gardens.

The proportion of farms that fell into recommended soil macronutrient thresholds for cocoa for Ghana and Indonesia (as proposed by Snoek *et al*., 2016) is summarised in Table 3. A larger proportion of the farms in Indonesia had soil which was below the low pH threshold (i.e. excessively acid). In both Ghana and Indonesia a significant proportion of farms were below the proposed threshold for carbon and nitrogen. In both countries there was geographical variation in the levels of these nutrients, most noticeably in Indonesia with more recently established areas, such as those in Western Sumatra having higher carbon and nitrogen levels.

Table 2. Summary of differences between farms in Ghana, Côte d'Ivoire and Indonesia.

Characteristic	**Ghana**	**Côte d'Ivoire**	**Indonesia**
Farm size (ha) (mean and range)	2.17 (0.26 to 11.6)	2.80 (0.44 to 14.8)	0.7 (0.11 to 3.2)
Farm Age (years) (mean and range)	17.5 (1 to 52)	24 (4 to 56)	15 (2 to 34)
Cocoa density (tree ha^{-1}) (mean and range)	1244 (276 to 3626)	975 (556 to 1848)	888 (272 to 2598)
Regular planting	Very few	None	Most
Planting material	100% seed derived	100% seed derived	Mixture of seed-derived and clonal material

Table 3. Proportion of farms that fell into the recommended soil macronutrient thresholds for cocoa as proposed by Snoek *et al*. (2016). "Gh"= Ghana, "Ind"=Indonesia

Parameter	Unit	Lower threshold (L.T)	Upper threshold (U.T.)	Farms below L.T. (%)		Farms above U.T. (%)		Farms within range (%)	
				Gh	Ind	Gh	Ind	Gh	Ind
pH		5.1	7.0	16.7	40.8	3.1	0.8	80.2	58.3
C	%	1.7	3.2	72.9	57.5	0	0	27.1	100
N	%	0.2	0.4	83.3	60.0	0	10.8	16.7	29.2
P	mg kg^{-1}	12.0	25.0	39.6	**	21.9	**	38.5	**
K	$cmol_c\ kg^{-1}$	0.2	1.2	0	0.8	0	3.3	100.0	95.8
Mg	$cmol_c\ kg^{-1}$	0.9	4.0	32.3	10.0	3.1	27.5	64.6	62.5

**The technique employed here did not allow for comparison with the Snoeck *et al*. (2016) recommendations

Yield Variability

Average yields in Côte d'Ivoire, Ghana and Indonesia are shown in Table 4. On average, yields were highest in Indonesia. Yields varied considerably between farms, the largest amount of yield variation was observed in Indonesia, which was greater than 100-fold for the years 2015/16 and 2016/17.

Fitted models obtained through multiple regression analysis accounted for between 35 and 69 % of farm-to-farm variation in yields. An example of modelled yield vs actual yield is shown in Figure 1 for Ghana for the year 2012/13. Farm to farm variation in yields was partially explained by a small number of common factors in each country. A small negative impact of an increase in cocoa tree density was sometimes observed in Ghana and Indonesia, although when extrapolated to an area basis, the impact of increasing tree density on yield per hectare was positive. A positive impact of fertiliser application on yields was detected in the models for both Ghana and Indonesia, whilst a positive impact of spraying fungicides against blackpod was also observed in all three countries. In Ghana, insufficient soil phosphorus was another factor underlying yield variation between farms.

Table 4. Summary of yield variation between farms in Côte d'Ivoire, Ghana and Indonesia

Country	Year	Number of farms	Mean yield ($kg\ ha^{-1}\ yr^{-1}$)	Ratio of highest to lowest yielding farm
Côte d'Ivoire	2016	48	552	14
Ghana	2012/13	96	725	30
	2013/14	96	781	10
	2015	48	697	5
	2016	48	794	7
Indonesia	2014/15	120	1034	24
	2015/16	120	1229	137
	2016/17	120	1229	170

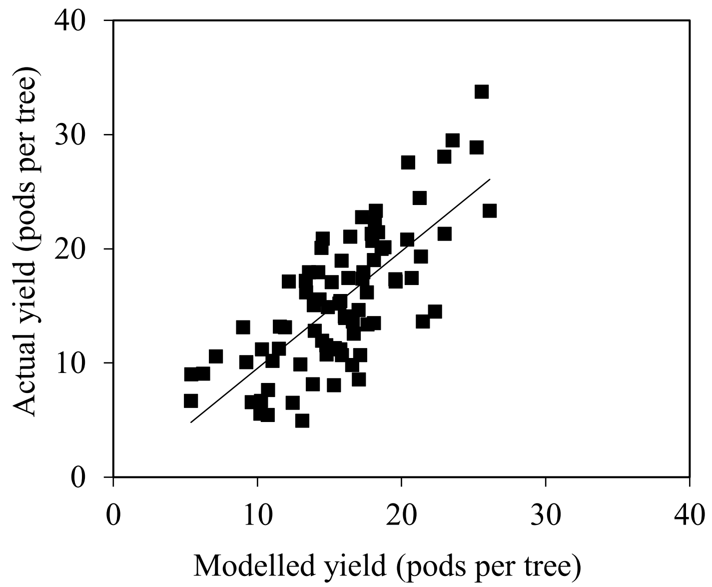

Figure 1: comparison of modelled yield data for the year 2012/13 across farms in Ghana compared with actual yield (expressed as pods per tree) ($r^2 = 0.56$).

Discussion

The study illustrated a considerable amount of farm-to-farm yield variation in each of the three top ranking cocoa-growing countries and thus indicates the potential for on-farm yield improvement. Furthermore, the observation that a high proportion of farmers over the age of 50 in Ghana and Indonesia (as observed also by Aneani *et al*., 2011 in Ghana) is illustrative of the need for cocoa-growing to be made more attractive, through improved technologies and yields, for future generations. The wide range of farm practices observed in this study points towards routes to yield improvement.

A key factor underlying farm-to-farm yield variability in all countries was planting density, with many farms under-planted (although it should be noted that the lower average planting density observed in Indonesia is likely to be a reflection of the fact that greater amounts of intercropping with other tree crop species was present). The results suggest a need to educate farmers better regarding optimal planting. Different cocoa genotypes are likely to be suited to different densities (Lockwood and Yin, 1996) and therefore as new hybrids and clones are developed there is a need for experimentation into their optimal density. A lack of uniformity in planting observed particularly in Côte d'Ivoire and also in Ghana may suggest a lack of appreciation of the benefits of planting in rows. Uniform spatial arrangement of trees has the advantage of reducing competition between trees (in terms of light, water and nutrition) and also making management of the crop easier (e.g. for spraying).

Another key factor underlying yield variation was whether or not farmers applied fertilisers. However, since fertilisers are a relatively expensive input, it is important that fertiliser recommendations are matched to local soil conditions, particularly given the fact that such a large amount of variability was observed in soil characteristics between farms in both Ghana and Indonesia. Excessive or inappropriate fertiliser use is not only cost ineffective but also can result in leaching of nutrients. It was noticeable, in both countries, that more recently established areas (such as Western Sumatra in Indonesia) had higher levels of carbon and nitrogen. Maintenance of soil organic matter is particularly important given that soils with a higher organic matter generally can have better nutrient and water retention properties (Hudson, 1994). In Ghana, a consistent association was observed between soil phosphorus levels and yields, which reflects the fact that high levels of soil degradation have resulted in this nutrient being limited on some farms.

The positive association between spraying with fungicides against blackpod and yields indicates that a large proportion of the crop can be lost to this disease. No association was observed between insecticide application and yields in the three countries, which may be a reflection of inefficient practices in place. For example, in Ghana it was observed that many farmers were not making spray applications (against mirids) at the recommended time of the year.

Generally the regression models did not pick out a strong relationship between variety and yield. This may be because many farmers cultivate a mixture of different varieties (for example, in Ghana mixed hybrids are distributed from seed gardens) and that the yield potential of a particular variety may not be expressed if the management or soil conditions are not optimal. Numerous studies have illustrated genotypic differences in yields in cocoa when grown under experimental (usually optimal) conditions (e.g. Lockwood, 1975) and therefore it would be expected that cultivation of improved varieties would contribute to better on-farm yields. However, the results of this study illustrate a particular need in Côte d'Ivoire and Ghana to educate farmers on the importance of obtaining seed stock from recommended seed gardens.

To conclude, the results of this study demonstrated the potential for yield improvement on existing farms, without significant expansion of the area cultivated, through husbandry practices (such as gap-filling/ replanting of low density farms), targeted fertiliser application and carefully timed pest and disease control.

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