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How many years of evaluation are needed to select new productive cocoa clones?

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ABSTRACT

In perennial plants, the selection of new genotypes requires several years of evaluation to get a reliable estimate of the genetic value and performance potential of the trees. The cocoa tree, which is cultivated for its beans, produces continuously throughout the entire duration of trial plots or field stands, which can last up to 30 years. The genetic value of the trees' productivity over the entire production period is therefore difficult to assess. In particular, how many years are needed to estimate the potential of the trees? To answer this question, the analysis of a trial comparing 42 clones in a statistical design, located in Costa Rica, was proposed. The individual production of each of the 1187 trees in this trial was evaluated over 18 consecutive years. Results indicate that the first year's production is not a reliable predictor of cumulative production over 18 years given its genetic correlation of 0.68. It is necessary to have an accumulation of 4 years for the genetic correlation with the 18-year accumulation to be higher than 0.85, and an accumulation of 7 years for the genetic correlation to be higher than 0.90. Longitudinal data analysis allows for a better understanding of the links between production of the successive years. In this trial, the seventh year was a year of high production followed by a slight decrease in the eighth year. Determining an evaluation period that allows for a reliable estimate of genetic value should therefore be based on the study of production kinetics. Indeed, it seems necessary to continue the evaluation of tree production until a high annual production that reveals the productive capacity of the genotypes. Studies on production kinetics also make it possible to envisage genetic improvement for better sustainability of cocoa trees to be proposed in appropriate cropping systems.

Key-words: cocoa production kinetics, selection strategy, sustainability

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1. Introduction

Cocoa trees, grown for their beans, are perennial plants that produce for many years. The number of years in production varies significantly, depending on sanitary and climatic pressures, on soils, and on varieties. There is very little information on the life expectancy of trees and the life span of plantations. Yield, estimated in the first few years of production, is the major selection criterion for many countries. Production stability over time, and duration of production are generally not considered, as these are difficult traits to assess as for many perennial species (Alves et al., 2018; Cilas et al., 2003; Cilas et al., 2011). Also, although productivity is a key trait, cacao breeders need to consider other traits affecting performance including, vigour, disease resistance, drought and heat tolerance, pollen compatibility and organoleptic properties of the beans.

Estimating yields in the first 4-5 years of production allows selection of early-maturing varieties, but how many years of observation are needed to select the most productive varieties over the longer life-span of the plantations. The objective of this study is to determine the number of years of observation needed to predict the productive capacity of cocoa trees over the long term. For this purpose, the production of a comparative trial of clones was monitored for 18 consecutive years.

2. Materials and methods

2.1. Plant material and experimental design

The observations took place for eighteen consecutive years, from 2001 to 2018, in a cocoa clone trial at the CATIE experimental farm 'La Lola'. The farm is located in Costa Rica, in the province of Limon, canton of Matina, at an altitude of 40 m. In this trial, 46 clones were planted in 1998-1999, in a complete block design, with four randomized blocks and elementary plots of 8 trees for each clone. The spacing between the trees was three metres. Some trees died and were not included in the analyses. The number of living trees varied between clones from 5 to 32 at the end of the study in 2018. A fertilisation of 600 gr of 18-5-15-6-0.3-7 per tree per year was applied, as well as manual weeding every 2 months plus 2 applications of herbicide per year. The clones (Table 1) were selected mainly because they are tolerant to monilia (*Monilinia spp*.), black pod rot (*Phytophthora spp.)* or witches' broom (*Moniliophthora perniciosa*) and/or are highly productive; however, monilia-tolerant clones for which there was no information on their productive potential predominate in the trial (Phillips-Mora et al., 2005; Phillips-Mora et al., 2013).

2.2. Data and statistical analyses

Numbers of healthy pods produced per tree each year (18) were recorded. The data analysed were the annual production of healthy pods and the cumulative production of the 18 years, i.e. 19 traits in total

Each trait was defined by tree, and a mixed model of analysis of variance, with block as fixed effect and clone as random, was performed for each trait to estimate genetic and environmental variances. The broad sense heritability for each trait was estimated by the ratios of estimated genetic variances and phenotypic variances (Falconer 1974).

$$h_b^2 = \frac{\sigma_G^2}{\sigma_P^2} = \frac{\sigma_c^2}{\sigma_c^2 + \sigma_e^2}$$

Where: h_b^2 = broad sense heritability,

σ_G^2 and σ_P^2 are respectively genetic and phenotypic variances,

σ_c^2 and σ_e^2 are respectively clone and error variances

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Then, genetic correlations were estimated between sum of annual yields (from 1 to 16) and cumulated yields on the 18 years.

3. Results and discussion

The production of healthy pods increases during the first 7 years from 2 to more than 18 pods per tree on average (table 2). Thereafter it varies around a plateau (between 12 and 21 pods per year) and then falls slightly from the fifteenth year onwards.

Annual production heritability varied from 0.26 in the first year to 0.46 at full production (Table 2). Heritability was variable during the first 6 years and then remained above 0.35.

Table 2: Broad sense heritability of annual productions and 18-year cumulative production

	Healthy pods (HP)	
Year	Mean	h^2_B (95% confidence limits)
1	2.0	0.26 (0.18, 0.36)
2	3.5	0.33 (0.23, 0.43)
3	4.7	0.27 (0.18, 0.37)
4	9.5	0.40 (0.29, 0.50)
5	7.9	0.27 (0.17, 0.36)
6	12.5	0.28 (0.19, 0.38)
7	18.3	0.35 (0.25, 0.46)
8	15.5	0.36 (0.26, 0.47)
9	15.9	0.41 (0.30, 0.51)
10	12.4	0.41 (0.30, 0.51)
11	12.2	0.40 (0.29, 0.51)
12	20.9	0.35 (0.24, 0.45)
13	15.2	0.37 (0.27, 0.48)
14	17.2	0.39 (0.28, 0.49)
15	9.8	0.40 (0.30, 0.51)
16	11.1	0.39 (0.29, 0.50)
17	11.2	0.41 (0.30, 0.52)
18	8.0	0.46 (0.35, 0.57)
1-18	207.8	0.52 (0.41, 0.63)

Cumulative production has the highest heritability; this trait reflects more the productive capacity of the clones.

The prediction of cumulative production over the 18 years becomes satisfactory from the 7th year onwards, with a genetic correlation between the first 7 years' cumulative production and the 18-year cumulative production greater than 0.9 (Figure 1). If the measurements are stopped in year 4 of production (6 years after planting), the genetic correlation with the 18-year cumulative production is less than 0.9.

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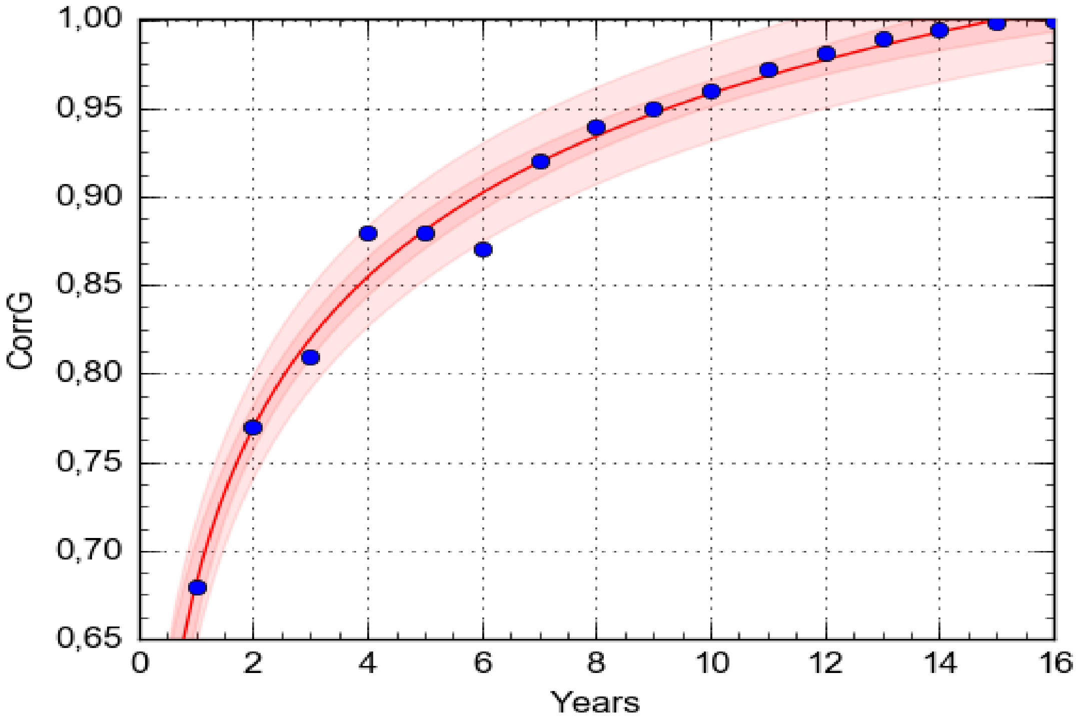

Figure 1: Genetic correlations between the sum of the annual productions $\sum_1^x HP$ and the cumulative production over the 18 years.

A minimum of 7 years of observation seems therefore necessary to predict the productive capacity of the clones.

4. Conclusions and recommendations

Broad sense heritability values for annual productions (HP) were low to medium (Table 2) with values between 0.26 and 0.46; and the trait with the highest heritability (0.52) was the cumulative yield over the 18 years, with a smoothing of the annual effects, as it was already observed for a factorial mating design in Côte d'Ivoire (Tahi et al., 2019).

The estimation of genetic correlations makes it possible to determine a number of years required to satisfactorily predict cumulative production. Seven years of observation provides a good estimate of cumulative production over the 18 years (Figure 1).

Generally, it seems necessary to continue the evaluation of tree production until a high annual production that reveals the productive capacity of the genotypes. Studies on production kinetics also make it possible to envisage genetic improvement for better sustainability of cocoa trees to be proposed in appropriate cropping systems.

Another way would be to better understand the elaboration of yield in order to approach the elementary traits that make it up. Indeed, yield is a complex of component traits, including: number of pods x number of seeds per pod x seed weight (Cilas et al., 2010; Doare et al., 2020). The main trait, the number of produced pods, depends on flowering, pollination, cherelle wilt, and pest and disease pressure.

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