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Effectiveness of juvenile tree growth rate as an index for selecting high yielding cocoa families

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ABSTRACT

Understanding the relationship between vegetative vigor and productivity in cocoa is critical to maximizing yield per unit area in cocoa plantations. Three trials established from either progenies of self mating of 24 clones of Upper Amazon origin, or from progenies of mating among clones recommended as parents for production (Seed Garden clones) or from progenies of inter- and intra-group mating of selected clones were analyzed for their vigor and yield relationships over a period of 10 years. The rate of increase in tree trunk cross-sectional area (TCSA) prior to bearing was an effective parameter in identifying families with large cumulative yields over the first five or six production years. Families with slow increase in juvenile TCSA were particularly of low bean yields. Though girth of adult trees was generally correlated with cumulative yields, a consistent relationship between tree girth at the end of the 10th year and yield efficiency was not observed. Yield efficiency was significantly correlated with cumulative yield, and showed predominantly additive gene action. The combined selection for rapid increase in juvenile tree TCSA and precocity have the potential of identifying high yielding families early in a cocoa breeding program.

1. Introduction

Selection for high bean yield is a central objective in cocoa (*Theobroma cacao* L.) breeding programmes worldwide. In West Africa, much of the yield improvement in the early years of formal cocoa breeding research was attributable to introduction of germplasm of Upper Amazon origin that were also of higher vigor compared to the West African Amelonado type that dominated production (Glendinning, 1967; Posnette, 1951). With the Amelonado types, high population densities of up to 2700 trees/ha were used (Van Hall, 1932). However, consistent with their higher vigor, a lower cropping density of 1111 trees/ha has been recommended for production (Manu and Tetteh, 1987). With the broadening of the genetic base following the introduction of the more heterozygous Upper Amazon genotypes, the uniformity of cocoa trees associated with the Amelonado types was reduced (Lockwood, 1976), and complicated the patterns of inter-plant competition in plantations (Glendinning and Vernon, 1965). Lachenaud and Montagnon (2002) and Adomako and Adu-Ampomah (2005) studied differences in vigor of individual trees in full-sib families and observed that high coefficient of variation in tree-to-tree bean yields were related to differences in tree vigor.

Trunk cross-sectional area, referred to as the intensity of vegetative growth (Nesme et al., 2005), provides integrative information about whole tree growth and it is the commonest variable used to estimate cumulative growth over long periods in tree species (Barden et al., 2002; Lachenaud et al., 2007; Reddy et al., 2003). Given the importance of the relationship between vegetative vigor and productivity in cocoa, a composite selection criterion termed cropping efficiency or yield efficiency has frequently been used (Daymond et al., 2002; Lotodé and Lachenaud, 1988; Pang, 2006). Daymond et al. (2002) defined yield efficiency as the ratio of the cumulative yield over a period of time to increment in trunk cross-sectional area over the same period. As with annual crops with high harvest index, cocoa families with high yield efficiency partition a larger proportion of assimilates to reproduction than to increment in vegetative biomass during the reproductive phase. Aside the key criterion of selecting precocious bearing clones with moderate vigor (Posnette, 1982), the use of dwarfing mutant rootstock (Adu-Ampomah et al., 2005; Tukey, 1993), chemical growth regulators (Erez, 1984) and restriction of root growth (Atkinson and Else, 2005) have been suggested to reduce tree size and increase yield efficiency. As observed in other perennial crops, the combination of small tree size and high yield efficiency provides the potential for higher yield per unit area (Lachenaud and Oliver, 1998; Larsen

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et al., 1992). Matching tree vigor to appropriate planting density is recognized as the key step to increasing yield efficiency, yet, the universal interaction that exists between clone and planting density for yield (Mooleedhar and Lauckner, 1990; Lockwood and Pang, 1996) complicates decisions on the appropriate planting density to maximize yield efficiency.

This study focuses on three field breeding trials established under the CFC/ICCO/Bioversity International project with the overall objective of selecting high yielding families for recommending to farmers (Eskes, 2011). To achieve this objective, several growth and yield related datasets including vegetative growth rate that was estimated from trunk girth increments were recorded. The objective of the current analyses was to examine the implications of juvenile tree vigor on reproductive efficiency among cocoa families. Specifically, the paper examines whether the juvenile tree growth rate estimated as girth increment over time have value for selecting precocious and high yielding cocoa families.

2. Materials and methods

2.1. Genetic material and trial establishment

Three sets of field experiments, designated A, B, and C were used in these analyses. In experiment A, the families consists of progenies of 25 crosses advanced from parents that have been shown in earlier studies to have good GCAs for yield and resistance to black pod disease (Adomako et al., 1999). Majority of these clones are recommended as parents for production and used as Seed Garden parents (referred hereafter as Seed Garden clones). The experiment was designed to accumulate favorable alleles for bean yield and black pod resistance in the progenies, and to develop clonal planting material from the best performing families. In experiment B, 24 progenies derived from self mating of each of 24 clones comprising six clones from each of four genetic groups being the Nanay (Na), Parinari (Pa), Iquitos Mixed Calabacillo (IMC) or Trinidad introductions (T) were studied. The clones in the T genetic group were derived from crosses between the Na, Pa and IMC genetic groups. Being generally self-incompatible, self mating was done with a ratio of 1:1 mixture of compatible mentor pollen (clone P 30, West African Amelonado) irradiated with gamma rays at 60 Gy and normal self pollen for the particular test clone. Experiment C comprise progenies of inter population or intra population mating of the Na, Pa, IMC and T clones. Forty families of which 24 were derived from inter-group crosses and 16 derived from intra-group crosses were studied. An additional cross, T 79/501 × Sca 6, was included to give a total of 41 outcross families. This family was also included among the set of families derived from the Seed Garden clones to serve as a common control variety.

Except for P 30 (West African Amelonado), all parental clones are of Upper Amazon origin. Following manual pollination, seed pods were harvested at maturity, and seedlings from these were nursed for six months before transplanting in the field.

The three experiments reported in this study were planted at the experimental fields of the Cocoa Research Institute of Ghana (CRIG), Tafo (latitude 06°13′N, longitude 0°22′W) in the Eastern Region of Ghana. Families from experiment A were planted in July, 1998 whereas the other two trials were planted in July 1999. The three trials were established separately in adjacent blocks. For each trial, seedlings were established at 2.5 m × 2.5 m (1600 trees/ha), in two rows of five plants per row. Within each field trial, the design was a randomized complete block with six replicates, though only the first four replicates were analyzed for this study because the fifth and sixth replicates in each trial were established 12 months later. Each trial was surrounded by two rows of boarder trees.

2.2. Crop measurements

Seedling diameter at 15 cm above the soil surface was measured with electronic callipers, typically at six-monthly intervals, starting from nine or 10 months after transplanting. Measurements were taken for a period of 24 months after the initial recording. Adult tree circumference was also measured at 15 cm above the soil surface at the end of the 2008/2009 cropping season in March 2009.

Bean yield data were recorded on each of the 10 trees in a plot from April 2003 to March 2009 for families in experiment A, and from April 2004 to March 2009 for the two other trials. Recorded traits included total number of matured pods, number of matured pods damaged by pod rot, the number of immature-ripe pods, and number of pods damaged by rodents. The number of pods damaged by pod rot (black pod symptoms typically caused by *Phytophthora* spp.) was divided into useable blacks and discarded blacks. Yield of dry beans per hectare from each progeny was estimated from total useable pod production (the sum of healthy and useable black pods) divided by the pod value estimated for each progeny separately. The first production year was taken as the year the highest yielding progenies first recorded dry bean yields of at least 200 kg/ha. Precocity was then defined as the yield of a family for the first production year. The trunk cross-sectional area was estimated from the tree trunk girth measurements. Yield efficiency was calculated as the cumulative yield per tree from the commencement of bearing to the conclusion of recording divided by the trunk cross-sectional area at the end of yield recording period in March 2009.

2.3. Data analysis

Analysis of variance (anova) was used to assess differences between progenies for each trait evaluated in the trial following tests for normality. All analyses were performed in GenStat Statistical package Version 11 (VSN 2008). A mixed model (REML) repeated measures approach, following the autoregressive model of order 1 [(AR (1))] was used to determine differences between progenies. To assess the effects of retrospective selection for bean yield based on seedling growth rate we used a *t*-test to assess differences in bean yield of two sets of families with contrasting seedling girth increments. For each trial, the first set was composed of the family

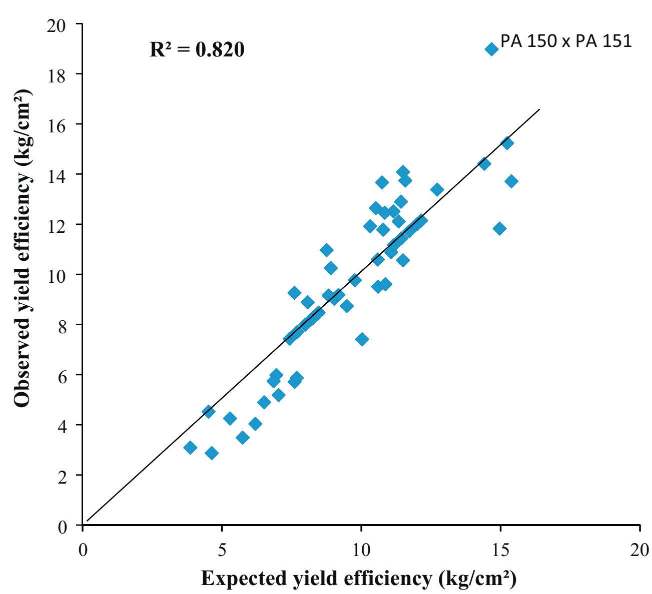

Fig. 1. Combining abilities for yield efficiency among cocoa progenies obtained from observed values of progenies plotted against expected values from parental general combining ability (experiment C).