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EFFECT OF PLANTING DENSITY ON YIELD AND INCIDENCE OF WITCHES' BROOM DISEASE IN A YOUNG PLANTATION OF HYBRID CACAO TREES

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SUMMARY

The effect of seven planting densities on yield and witches' broom disease incidence in hybrid cacao (*Theobroma cacao*) trees in the Brazilian Amazon was investigated. Data collected over a three-year period showed that it was possible to optimize regional cacao yield by high planting densities (2500 and 1666 trees ha^{-1}) and that there was no density × year interaction. However, high planting density also favoured witches' broom incidence. A growing regional interest in planting cacao clones at high planting density should be pursued with caution, since high planting densities of clones in environments under strong pressure of selection for the witches' broom pathogen, such as in the Amazon region, are still a risky strategy. Alternatives to the high planting density system are presented and discussed.

INTRODUCTION

The Brazilian Amazon cacao (*Theobroma cacao*) planting had as its model the system of the Bahia cacao region. Thus, all planting was at a spacing 3.0 × 3.0 m (1111 trees ha^{-1}), except for some regions in Rondônia (Ouro Preto do Oeste) and Pará (Tomé-Açu) states where cacao trees were spaced at 2.5 × 2.5 m (1600 trees ha^{-1}). However, the vegetative vigour of the Brazilian Amazon cacao trees and the witches' broom sanitation control methods (for example, pruning) have demonstrated the need for a change in the production system, especially in planting density. Witches' broom, a disease caused by the fungus *Crinipellis perniciosa*, is the main disease in the Brazilian cacao regions and the north of South America. This disease is responsible for a yield loss of 30% on average, reaching 90% loss in cacao areas without control (Luz *et al.*, 1997). The pathogen

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C. perniciosa causes overdevelopment of cacao meristematic tissues leading to hypertrophied growth, conferring on the shoots the characteristic appearance of a broom. The fruits and seeds are also infected by the fungus, undergoing necrosis with loss of commercial value. Disease control measures are sanitation pruning, using resistant genotypes and chemical control. The latter is only practised in some States of the Amazon.

Early results of regional research have shown that high planting density favours witches' broom incidence, regardless of the cacao genotype. High planting density induces the cacao trees to grow tall, making pruning difficult and increasing disease control costs. Such costs may reach 20% to 25% of the income generated by the cacao crop in the region. Cacao fruit distribution is also related to planting density. High planting density promotes higher concentration of fruits on the trunks and lower concentration on the lateral branches, with the opposite occurring at low planting density (Alvim, 1964). However, cacao height does not seem to increase fruit yield significantly. On the other hand, the low tree height favours the formation of lateral branches and facilitates witches' broom sanitation control.

There is currently a growing interest in the establishment of cacao crops at high density by using high yielding clones. This production system has already been successfully used in Indonesia (Wood and Lass, 1985) and Malaysia (Lockwood and Pang, 1996) and may be recommended in the cacao regions of the States of Rondônia (Laker and Mota, 1990) and Bahia (Luz *et al.*, 1997), in which cases productive clones tolerant to witches' broom disease should be used. In the past, high planting density was also used by cacao growers in Ghana and Nigeria, who used spacing ranging from 1.5 to 2.4 m between trees (Alvim, 1964). However, high planting density has a considerable effect on yield which is closely connected with age. High density seems to result in high yields only during the first years of cropping (Freeman, 1929; Kowal, 1959), with a significant planting density × clone interaction (Lockwood and Pang, 1996). Furthermore, the effects of the higher planting densities on yield and levels of *C. perniciosa* infection in cacao crops with high occurrence of this pathogen are not well understood. This work aims to examine the effect of seven planting densities on the yield and incidence of witches' broom in young (at six years after planting) hybrid cacao trees in the Brazilian Amazon as well as the interaction of this effect with age.

MATERIALS AND METHODS

The trial was set up during January and February 1991 at the Estação Experimental Ouro Preto (ESEOP) which is part of the Experimental Stations Net of the Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC). The ESEOP is located in Ouro Preto do Oeste, Rondônia, Brazil (lat 10° 42′ S, long 62° 14′ W, altitude 240 m asl), under climatic conditions similar to those found in the state's cacao regions. The hot humid tropical savanna climate (Köppen

Aw climate type) is characterized by 1971 mm mean annual rainfall, concentrated from November to April (80.5%) with a dry period between June and August. Relative humidity over the year exceeds 79% and the mean annual temperature is 24.5 °C. Soils present a B textural horizon and average natural fertility.

The genetic material used consisted of a mixture of three hybrids (SCA 6 × ICS 6, Pound 7 × BE 10 and SIAL 505 × MA 15) produced by controlled pollination at the seed orchards of CEPLAC. These hybrids were under agronomic evaluation in regional trials conducted at the time this trial was established. CEPLAC is responsible for the production and distribution of hybrid seeds which are donated to cacao growers for planting. Due to the presence of several incompatible alleles in some parental clones of the hybrids, a combination of genetic materials is distributed, often consisting of five or more bi-clonal hybrids. Therefore, the use of a mixture of hybrids in this experiment has met the genetic breeding programme strategies applied to expand cacao production in the Brazilian Amazon. As temporary shade, bananas (*Musa* spp.) were planted at the same densities as the cacao trees. The experimental area was practically without shading, for the growth of mahogany (*Swietenia macrophylla*), which was planted as permanent shade, had been jeopardized by the cedar borer (*Hypsipyla grandella*). All the handling practices planned for the crop, including removal of vegetative and cushion brooms, were carried out annually, except for fertilization. The experiment was designed as a randomized complete block with six replications and plots of 288 m^2. Plots were surrounded by a single guard row between them. There were seven treatments representing different planting densities, as described below:

(1) 2500 cacao trees per hectare (2.0 × 2.0 m)
(2) 1666 cacao trees per hectare (2.0 m with alternate 2-m and 4-m spaces between rows)
(3) 1250 cacao trees per hectare (2.0 × 4.0 m)
(4) 1111 cacao trees per hectare (3.0 × 3.0 m) (used as a pattern of conventional planting density)
(5) 800 cacao trees per hectare (2.5 × 5.0 m)
(6) 833 cacao trees per hectare (3.0 × 4.0 m)
(7) 625 cacao trees per hectare (4.0 × 4.0 m)

Harvesting began in February 1995 and was carried out monthly for three years (1995–1997). At each harvest, the total number of fruits and the number of fruits infected with witches' broom per plot were recorded. To estimate the weight of fresh seeds, random samples of 50 healthy fruits were recorded each month from the trial as a whole. Since the plant material was formed from the same hybrid mixture this sampling method was found to be adequate. Each year the real number of trees per plot (stand) was recorded.

Analyses of variance were performed for yield component data from each year. Due to the homogeneity of the experimental error variances found in the annual analyses (1995, 1996 and 1997), the yield component data accumulated over three years were combined in joint analyses of variance. These joint analyses allowed density × year interaction to be investigated. The yield component data analysed were the total number of fruits per hectare (TNFH), the number of healthy fruits per hectare (NHFH), the wet seed weight per hectare (WSWH), and the percentage of diseased fruits (PDF). TNFH was calculated by multiplying the total number of fruits per plot by the corresponding plant density per hectare, and taking the ratio between this result and the respective stand; NHFH was generated in an analogous fashion. TNFH and NHFH represent respectively the potential and real production. Moreover, there is a high genetic correlation (0.84) between NHFH and the dry bean yield per tree (Almeida *et al.*, 1994). The wet seed weight per plot was generated by multiplying the number of healthy fruits by the wet seed weight of the random samples of 50 fruits and WSWH was estimated similarly to TNFH and NHFH. PDF represents the ratio between the number of fruits infected with witches' broom per hectare and TNFH. Although important, the sampling procedure used to estimate the weight of humid seeds prevented the investigation of the effect of planting density on the wet seed weight per fruit.

Differences between year means were compared by the Tukey test, using the least significant differences (l.s.d.) at a probability level of $p < 0.05$. By comparing all the means of planting densities with the normal planting pattern (1111 cacao trees ha^{-1} or 3.0 × 3.0 m) the test of Dunnett (Steel and Torrie, 1980) was applied with the l.s.d. at the same probability level.

RESULTS

Highly significant ($p < 0.01$) differences between the planting densities were observed for all the yield components. Conversely, significant ($p < 0.05$) differences between the years were shown only for WSWH and PDF. The coefficients of variation obtained ranged from 28.6% for PDF to 35.2% for TNFH, which are of the same order of magnitude as those obtained in cacao trials (Dias and Kageyama, 1995). PDF changed over the years, probably due to the occurrence of climatic conditions favourable to the dissemination of *C. perniciosa*. Although the removal of brooms practised by pruning in the trial reduced PDF, it was not enough to promote reduction in the inoculum source. Significant density × year interactions were not detected. Densities and years were independent factors for all the yield components studied.

When the yield averages of the hybrid mixture obtained in the different densities were compared with the conventional density (1111 cacao trees ha^{-1} or 3.0 × 3.0 m) it was observed that for the averages of the first three years of the evaluation the high densities (2500 and 1666 cacao trees ha^{-1}) were significantly higher for TNFH (Table 1), NHFH (Table 2) and WSWH (Table 3). Similarly, the level of witches' broom incidence (PDF), differed statistically between the different planting densities, being highest at 2500 cacao trees ha^{-1} (Table 4).

Table 1. Mean total numbers (10^3) of fruit per hectare produced in a cacao hybrid mixture evaluated at seven planting densities (1995–1997) in Rondônia, Brazil.

	Planting density (trees ha^{-1})							
	2500	1666	1250	1111	800	833	625	Mean
1995	14.4	13.7	9.7	8.3	7.5	8.1	7.0	9.7
1996	12.2	12.0	8.1	8.2	7.9	9.2	6.9	9.2
1997	13.7	12.3	11.0	11.0	9.8	10.9	8.4	11.0
Mean	13.4	12.6	9.6	9.2	8.4	9.4	7.4	9.9
L.s.d. between densities: 3.1								
L.s.d. between years: 1.8								

Table 2. Mean numbers (10^3) of healthy fruits per hectare produced in a cacao hybrid mixture evaluated at seven planting densities (1995–1997) in Rondônia, Brazil.

	Planting density (trees ha^{-1})							
	2500	1666	1250	1111	800	833	625	Mean
1995	13.0	11.8	8.6	7.4	6.7	7.3	4.8	8.5
1996	10.2	10.3	7.4	7.2	7.0	8.1	6.3	8.1
1997	11.2	10.4	9.7	9.6	8.4	9.4	7.4	9.4
Mean	11.5	10.8	8.5	8.1	7.4	8.2	6.2	8.7
L.s.d. between densities: 2.6								
L.s.d. between years: 1.5								

Table 3. Mean wet seed weight (t ha^{-1}) produced in a cacao hybrid mixture evaluated at seven planting densities (1995–1997) in Rondônia, Brazil.

	Planting density (trees ha^{-1})							
	2500	1666	1250	1111	800	833	625	Mean
1995	1.3	1.2	0.9	0.8	0.7	0.7	0.5	0.9
1996	1.0	1.0	0.7	0.7	0.7	0.8	0.6	0.8
1997	1.1	1.1	1.0	1.0	0.9	1.0	0.8	1.0
Mean	1.1	1.1	0.9	0.8	0.8	0.8	0.6	0.9
L.s.d. between densities: 0.3								
L.s.d. between years: 0.2								

DISCUSSION

During the trial period the superior performance of high-density treatments for the first three yield components suggests that high planting densities would maximize yield in this region. In turn, the relative stability in time of the TNFH and NHFH conforms with the buffering presented by the hybrid mixture distributed to the cacao growers and already confirmed elsewhere (Dias *et al.*, 1998). However, since high density plantations (2500 cacao trees ha^{-1}) had

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Table 4. Mean percentages of diseased fruits produced in a cacao hybrid mixture evaluated at seven planting densities (1995–1997) in Rondônia, Brazil.

	Planting density (trees ha^{-1})							
	2500	1666	1250	1111	800	833	625	Mean
1995	10.2	10.0	12.1	11.6	10.6	9.5	9.5	10.5
1996	18.1	13.2	10.7	11.5	12.2	11.8	9.2	12.4
1997	21.2	17.0	15.6	13.2	13.8	14.5	12.1	15.4
Mean	16.5	13.4	12.8	12.1	12.2	11.9	10.2	12.7

L.s.d. between densities: 3.2
L.s.d. between years: 1.9

higher witches' broom incidence, yields might start to decline rapidly. Disease incidence increased with time at all planting densities. This may have been because larger, older trees had more meristematic tissue, which favoured both inoculum production and dissemination. Increase in intensity of the disease with age has also been observed in Ouro Preto do Oeste (Laker and Mota, 1990).

The superior performance of high density treatments in the first years of harvest corroborates other results (Freeman, 1929; Kowal, 1959). This suggests that although high-density plantations might initially maximize the cacao yield in the region, the damage caused by *C. perniciosa*, especially in fruits, might become worse as the plantation aged. It has already been noted that *Crinipellis* causes uncommonly high fruit losses in Rondônia State relative to vegetative infection (Evans, 1981).

The continuity of this experiment for a longer series of years until the mature tree yield period is reached (from the eighth to the tenth years of plantation), would allow the confirmation of such results. It might be expected that the competition among cacao trees would increase with ageing of the trees, favouring low-density planting and reducing the performance of the trees under high-density planting. In Trinidad, observations recorded by Freeman (1929) showed small differences in yield per tree up to the tenth year, but subsequently wide planting was associated with higher yields; those at 5.5 × 5.5 m at fifteen years producing approximately double the yield of those planted at 3.6 × 3.6 m. The expectation is the same in relation to the incidence of witches' broom. The annual averages for PDF (Table 4) reflect a significant increase in the values of that yield component in the treatments involving high densities in the years 1995–97.

The adoption of high-density plantations will demand short genotypes of superior performance. In physiological terms it is expected that dwarf cacao genotypes at high planting density will combine good light penetration with vigour. Different cacao genotypes need to be tested at different planting densities. The presence of clone × density interactions has been observed (Lockwood and Pang, 1996). Because cloning – a technique which is widely used in several cacao producing countries – leads to dwarf-stature plants, it will play an important role in this context. In Brazil, the commercial use of clones was started in 1957 with not very promising results. Dias (1993), after analysing the possible causes for the failure of the clonal plantations at the time and the potential represented by cloning, proposed to reincorporate it on cacao farms of a high technological level. Now, cloning is being put into practice (Luz *et al.*, 1997).

Seeds of the hybrid SCA 6 × ICS 1 and clones TSA and TSH are being produced commercially for replanting in areas infected by *C. perniciosa* in the south of Bahia. Clones of this hybrid SCA 6 × ICS 1 were recommended for plantations in Trinidad in the 1960s because they were productive and tolerant to witches' broom. However, this new production system demands a basic knowledge of research and growers of high technological competence (Dias, 1993) which presently are rare in cacao production. The existence of pathogenic races different from *C. perniciosa* (Laker, 1990), along with the evidence of a differential behaviour of cacao clones to infection from these races (Wheeler and Mepsted, 1982), may lead to a decrease in resistance to witches' broom as cacao ages. In the Brazilian Amazonian region, the progressive and accentuated mortality of adult cacao trees of the hybrid SCA 6 × ICS 1 (Machado *et al.*, 1992) are examples of the degree of complexity of this matter. This same hybrid when planted at high density in the south of Bahia is infected strongly by the pathogen *Ceratocystis fimbriata*. The high-density plantation with the use of clones in an environment under strong selection pressure for *C. perniciosa*, as in the Amazon and Southern Bahia regions, is still a risk strategy and with unexpected consequences in the short and long terms.

The agroforestry systems constitute quite satisfactory alternatives to high-density planting. In this situation, cacao would not be planted in monocrop but rather combined with forest species and fruit trees of economic value. Although its yield is lower, since the plantation density in these systems is generally reduced (usually 400 cacao trees ha^{-1}, when combined with rubber trees or 1111 cacao trees ha^{-1} combined with forest species), the income loss can be offset by the yield of the other crop. Under this system, the producer becomes less vulnerable to fall in prices of either of the products. On the other hand, witches' broom incidence in the cacao trees is smaller in low-density plantations (Table 4), which reflects a more balanced cultivation with characteristics of self-sustainability. The annual mean yield in the present trial (Table 3) was only 0.9 t ha^{-1} wet cacao which is about 0.4 t ha^{-1} dry cacao. Although this yield can be classified as low it was obtained without the use of the fertilization. Dry cacao yields of 2.5 t ha^{-1} or even up to 3.0 t ha^{-1} with hybrid mixtures in most favoured environments, especially in those without witches' broom incidence, are possible (Dias *et al.*, 1998). Promising results with cacao trees combined with other crops are beginning to be obtained in Rondônia (Almeida *et al.*, 1995).

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