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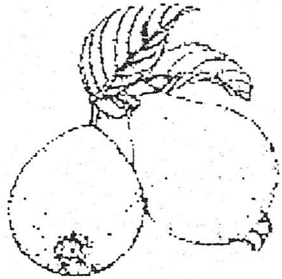

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STUDIES ON THE VARIABILITY OF CUPUAÇU PLANTS (*THEOBROMA GRANDIFLORUM* (WILLD. EX SPRENG.) SCHUM.) GROWING IN DIFFERENT CULTIVATION SYSTEMS ON A DEGRADED AREA: STATE OF DEVELOPMENT AND PRODUCTIVITY OF 3½ YEARS OLD TREES

UNTERSUCHUNGEN ZUR VARIABILITÄT VON CUPUAÇU-PFLANZEN (*THEOBROMA GRANDIFLORUM* (WILLD. EX SPRENG.) SCHUM.) IN UNTERSCHIEDLICHEN KULTURSYSTEMEN AUF EINER DEGRADIERTEN FLÄCHE: ENTWICKLUNGSZUSTAND UND PRODUKTIVITÄT 3½ JAHRE ALTER BÄUME

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Abstract

The cupuaçu tree (*Theobroma grandiflorum*, Sterculiaceae), native in the south-eastern terra-firme rain forest of the Amazon basin, is grown throughout the Amazon region as part of orchards or small scale production systems. The fruit pulp is used for the production of juices and other fresh products. The cultivation for commercial pulp production recently becomes more and more attractive. This tendency causes an increasing need for systematically selected breeding material. In co-operation with the EMBRAPA/CPAA (Manaus, Brazil) an additional use option, and thus, a new group of criteria for breeding is being investigated: the use of cupuaçu seeds for the production of a chocolate-like product. The ongoing biochemical analyses of the aroma potential of the seeds is paralleled by investigations concerning the variability of cupuaçu.

A stock of 750 seed derived cupuaçu plants, cultivated in different cropping systems on an experimental site near Manaus, Amazônia, is being studied. In this paper studies are presented regarding the variability of productivity and maturity of cupuaçu trees after 3½ years of cultivation. The results indicate that cupuaçu plants react very sensitive on even slightly varying site specific factors. This means that in practice the selecting and breeding of cupuaçu plants for high yield and rapid development require a detailed documentation of the environmental conditions, under which the quality determining characters had been observed.

Introduction

The cupuaçu tree, *Theobroma grandiflorum* (WILLD. ex SPRENG.) SCHUM., can be found as a natural constituent of the terra-firme rain forest of the south-east of Pará, Brazil, where it reaches a maximal height of about 20 m with a trichasiate ramification concentrated at the top (DUCKE 1953, VENTURIERI 1993). Cupuaçu trees cultivated in the plain sun or lightly shaded exhibit a diminution of the longitudinal growth favouring the intensity of ramification which leads to the formation of a more voluminous crown with a storeyed habitus (VENTURIERI 1993). In accordance with its natural occurrence the cultivation of cupuaçu is strongly restricted to the climate characteristics of the humid tropics as given in the Amazon basin.

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The morphological characteristics of the fruits, which have a weight of 1-2 kg and reach a length of 12-25 cm and a diameter of 10-15 cm, are quite similar to those of cocoa (*Theobroma cacao* L.): the pod, a capsular berry, consists of a lignified husk encasing 20-45 seeds which are surrounded by an aromatic pulp, which constitutes about 35-45% of the fruit's fresh weight.

The people living in the Amazonian interior distinguish two types of cupuaçu plants according to the appearance of the fruits (CALZAVARA et al. 1984): cupuaçu redondo, with more spherical, lateral slightly flattened fruits - the rife form of cupuaçu - , and cupuaçu mamorana, with more elongated fruits - the form with the biggest and heaviest fruits. In 1949 a spontaneous mutant was found in an orchard which bears fruits without developed seeds (VENTURIERI & MENDONÇA 1985). The nowadays cultivated seedless cupuaçu trees, which are all derived from this mutant, have been named cupuaçu mamau. These three types of fruit characteristics led to the actual definition of varieties of cupuaçu: C. redondo, C. mamorana, and C. mamau.

The pulp of cupuaçu fruits is used for the production of juice, ice-cream, and other fresh products. Present demand exceeds supply and is reflected in the relatively high market value of US$ 2-4 per kg pulp (LAKER & TREVISAN 1992, VENTURIERI 1993).

Some attempts dealing with the utilisation of the seeds, which amount to 15 - 20% of the fruit's fresh weight, revealed that in principle a chocolate like aroma can be obtained if the seeds are processed following the pattern for the processing of cocoa seeds (VENTURIERI & AGUIAR 1988, NAZARÉ et al. 1990). In addition to the problem to obtain a reproducible aroma there are also evident differences between the seeds of cocoa and cupuaçu which must be taken into consideration: e.g. the fatty acid composition of the seed fat (VASCONCELOS et al. 1975), the purine-alkaloids (BAUMANN & WANNER 1980, MARX & MAIA 1991, HAMMERSTONE et al. 1994), and the morphological characteristics of the seeds (e.g. seed dimensions, permeability of the testa).

Primary selected cupuaçu plants covering a wide range of variation can be found throughout the Amazon basin mainly cultivated as part of orchards or small scale production systems. The annual yield varies from 10 to 30 pods per adult tree leading to a productivity of 700 to 2800 $kg \cdot ha^{-1} \cdot a^{-1}$ (CALZAVARA et al. 1984, VENTURIERI 1993, FALCÃO & LLERAS 1983). Due to the high market value of the fruit pulp the cultivation of cupuaçu recently becomes more and more attractive, which, on the other hand, will lead to a reduction of price in the foreseeable future (LAKER & TREVISAN 1992, RIBEIRO 1994). Thus, there is a strong need to evaluate parameters for the selection and breeding of high yield planting material considering all potential use options. Furthermore special interest should be paid to the ecological requirements and field performance of particular strains and clones of cupuaçu in order to identify planting material adapted to the climatic and edaphic characteristics of particular localities - in the practice of cocoa breeding this necessity has been recognised very lately (HUNTER 1990). In addition to the criteria dealing with agricultural aspects and pulp production it is suggested to evaluate the potential use of the seeds for the production of a chocolate-like product. This use option, which means the supply of a separate market and the production of a storable ware, could contribute to the economic stability of existing and forthcoming cupuaçu plantations.

The joint research project of the University of Hamburg and the CPAA-EMBRAPA in Manaus, which is a part of the German-Brazilian SHIFT-program, is dealing with the following questions: Do cupuaçu seeds provide preconditions for the generation of aroma comparable to that of cocoa? Which ranges of variation can be found concerning those characters, which are considered to be determining factors for the cultivation and production? To which extent are these characters influenced by environmental factors?
Results concerning the variability of productivity and of the developmental state after 3½ years cultivation are presented here.

Materials and Methods

A stock of 750 seed derived cupuaçu plants has been studied which are cultivated as part of a recultivation experiment of a 19ha fallow rubber plantation on a former terra firme rain-forest area near Manaus (FELDMANN et al. 1995). The climate data measured near the experimental site (2°51' south, 59°52' west) since 1971 indicate the typical characteristics of humid tropics with no explicit dry season (CABRAL & DOZA 1993). Rainfall: 2500mm per annum, 300mm monthly maximum, 110mm monthly minimum. Air temperature: 24-26°C monthly averages, 30-33°C maxima, 21-23°C minima. Relative humidity: 87% monthly average maximum, 82% monthly average minimum.
The soil is characterised as xanthic ferralsol of low fertility and of a considerably high content of plant available aluminium (SCHMIDT 1993).
The experimental site has been divided into five repetition blocks (blocks A - E; see figure 1).

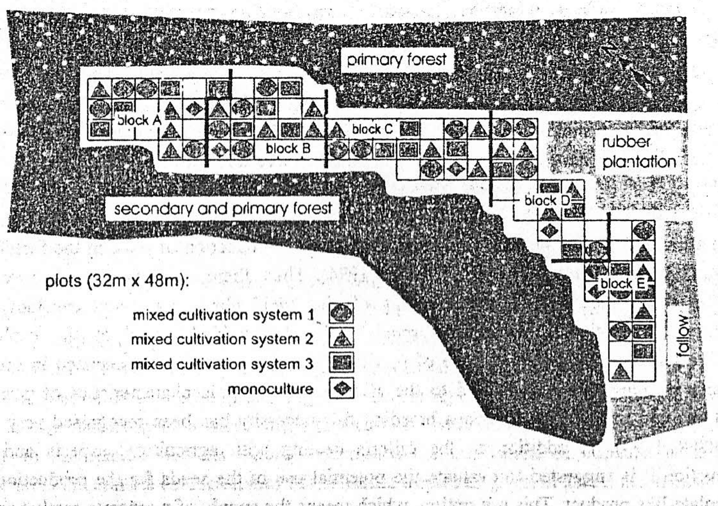

Figure 1: Scheme of the experimental area and its adjacent sites illustrating the topography and the (randomized) distribution of the different cultivation systems.

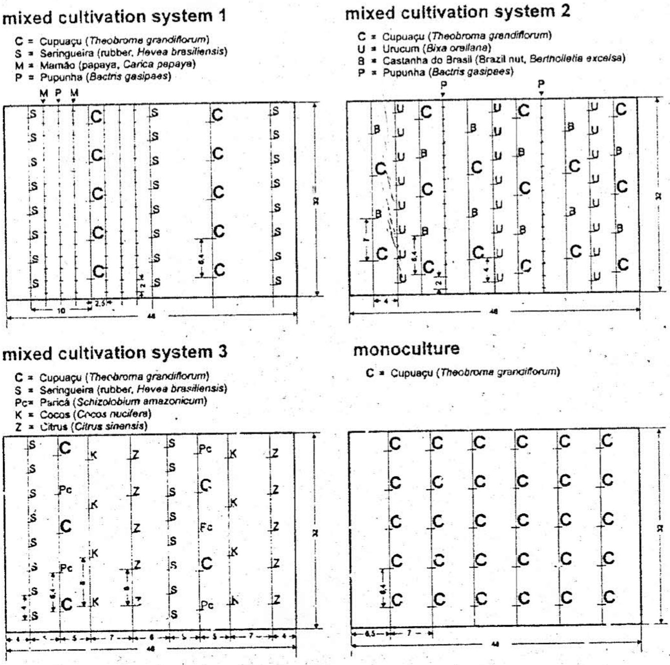

Figure 2: Plantation plans of the four tested cultivation systems (all dimensions in meters).

After slashing and burning of the fallow area cupuaçu seedlings have been planted in three mixed cultivation systems and one monocultural system in plots of 48m x 32m, each mixed cultivation system being represented four times in each block. The spacing and species compositions of the cultivation systems are presented in figure 2.
The seed material was provided by the CPAA-EMBRAPA and came of a germplasm of cupuaçu plants collected from different parts of the Amazon region. The exact descent of the seed material was not documented.
The fruit production has been recorded in terms of number of harvested fruits per tree and fresh weight of fruits. Every single cupuaçu plant has been monitored until March 1996. At this time all plants were 3½ years old.
The fruit production has been taken as measure to determine the maturity of the plants (no fruits = juvenile; fruiting = adult). From the adult plants those bearing 10 and more fruits per annum have been classified separately in order to register plants of advanced development.
The obtained data regarding productivity and development have been analysed in relation to the cultivation system, the position within the topography of the experimental site, and the distance to the adjacent forest.

Results

After 3½ years of cultivation the state of development and the productivity of the plants were considerably heterogeneous. 64.7% of the 750 plants did not yet enter the state of fructification, while 35.3% had reached their adult state. 12% of the adult trees had already attained an advanced state of development which is indicated by a productivity of more than 9 fruits per tree. A yield of that dimension is commonly expected after the fourth year of development or even later (VENTURIERI 1993, CALZAVARA et al. 1984). From the tree of the highest productivity 22 fruits had been harvested, a yield which lies in the range of the productivity of 6 years old, fully developed cupuaçu trees (FALCÃO & LLERAS 1983).

Comparing the developmental state and the productivity of the plants in the 4 cultivation systems it becomes evident that the mixed cropping systems obviously provide better conditions for the development of cupuaçu trees than the monoculture (figure 3 A). Especially system 1 is prominent regarding its high percentage of adult plants: 67.5% of the cupuaçu trees in system 1 were adult, 11.5% producing more than 9 fruits. Additionally, plants with exceptionally high yields (more than 16 fruits per tree) were found in system 1 only. In the monoculture, which was designed and handled according to common practices, 92.7% of the plants were still juvenile. Here, the tree with the maximum yield produced 3 fruits. The mixed cultivation systems 2 and 3 assume an intermediate attitude with a portion of adult trees of 28,7% and 24% respectively (figure 3 A).

Significant differences of the developmental state became also evident considering the different blocks of the experimental site. In the block E (southern part of the area) less than 10% of the cupuaçu trees had reached the reproductive stage after 3½ years of growth, whereas more than 50% of the plants in the block C has already been producing fruits (figure 3 B).

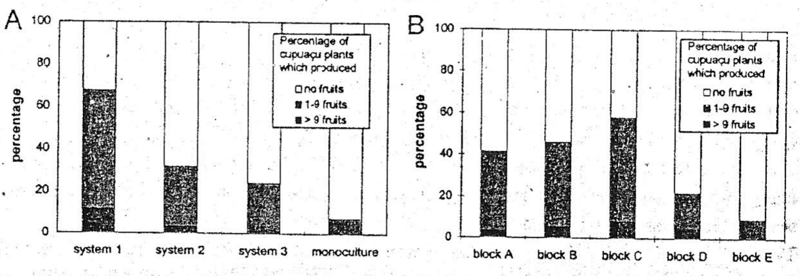

Figure 3: The developmental state of cupuaçu trees in terms of fruit production A) in the different cultivation systems; B) in different topographic blocks of the experimental site.

The fruit production has been recorded in terms of number of harvested fruits per tree. Every single cupuaçu plant has been monitored until March 1996. At this time all plants were 3½ years old. A: The graph shows for each tested cultivation system the portion of trees which produced no fruits, 1-9 fruits and more than 9 fruits (system 1: n = 200; system 2: n = 300; system 3: n = 100; monoculture: n = 150). B: The graph shows for each block the portion of trees which produced no fruits, 1-9 fruits and more than 9 fruits (each block: n = 150). 750 plants have been investigated.

This tendency, slowest development in block E and rapid development in block C, becomes even more evident if considering each cultivation system separately (figure 4). The unexpected differences of the developmental state between the blocks are probably caused by edaphic factors other than availability of macro-elements (which could not be correlated with the observed tendency).

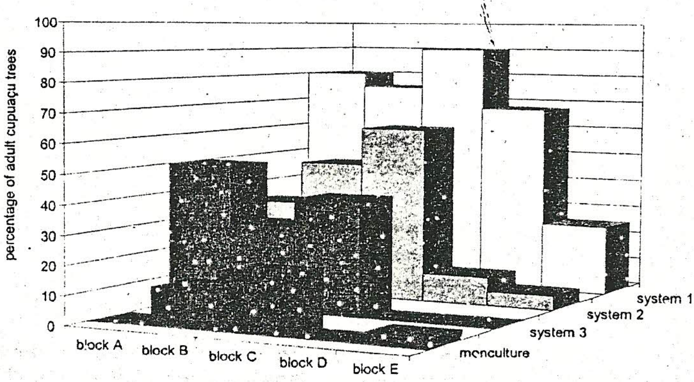

Figure 4: The percentage of adult cupuaçu trees (fruit producing plants) in the four cultivation systems at the different topographic blocks of the experimental site.
The fruit production has been recorded in terms of number of harvested fruits per tree. Every single cupuaçu plant has been monitored until March 1996. At this time all plants were 3½ years old. The graph shows for each system at the respective block the portion of trees which produced 1 fruit and more. 750 plants have been investigated.

In addition figure 4 illustrates the concurrent influences of cultivation system and the edaphic factors. It is remarkable that in block C even 90% of the trees of system 1 did attain the reproductive stage, whereas in block E the same system comprises only 25% adult trees. On the other hand system 1 is obviously most capable to compensate the unfavourable edaphic conditions given in the blocks D and E: in these blocks 46,3% of the trees in system 1 and only 2.5% (0% , 1.7%) of the trees in the system 2 (system 3, monoculture) are adult after 3½ years (figure 4).

Furthermore, our results suggest also an influence of the plants' distance to the secondary or primary forest (figure 5): there is a tendency that near the border of the experimental site the development of cupuaçu plants is advanced (68.8% adult trees), while in the central part of the field most of the plants have not yet reached the adult stage (30% adult trees). In addition none of the trees in the central part of the field did produce more than 9 fruits until the end of the investigations, while near the border more than 10% of trees produced 10 fruits and more (figure 5).

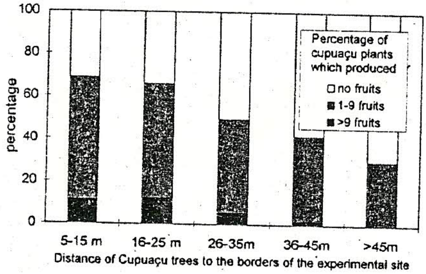

Figure 5: The developmental state of cupuaçu trees in terms of fruit production in different distances to the border of the experimental site. The fruit production has been recorded in terms of number of harvested fruits per tree. Every single cupuaçu plant has been monitored until March 1996. At this time all plants were 3½ years old.
The distances of the trees have been classified. The graph shows for each class of distance the portion of trees which produced no fruits, 1-9 fruits and more than 9 fruits. The plants in the mixed cultivation systems of the blocks A, B, C and D have been investigated (425 plants).

Discussion

It can be concluded that the differences in the development of cupuaçu plants after 3½ years growth is considerably influenced by slightly varying site specific factors which become perceptible on different levels:

a) growth conditions in the different cultivation systems
The tested mixed cropping systems obviously provide better conditions for the development of cupuaçu trees than the monoculture which has been conducted according to common practice. Particularly system 1 is prominent regarding its high percentage of adult plants surpassing even the mixed cultivation systems 2 and 3, especially in the blocks D and E. The main characteristics of system 1 distinguishing it from the other cultivation systems is the spacing to the next row and the species composition (table 1, cf. also figure 2).
It has been reported that during the first 2 years a direct shading favours the growth and development of cupuaçu plants (VENTURIERI 1993). However, although the distance between the rows in system 1 is very low (2.5m compared to 4m, 5m and 7m in the systems 2, 3 and the monoculture respectively) this did not yet lead to a direct shading of the cupuaçu plants. Thus, it is presumed that there are differences in the microclimatic conditions caused by the shade which covers a larger area in system 1 than in the other cultivation systems due to the higher planting density. This hypothesis must be verified by investigating particular microclimatic characters of the cultivation systems.

Table 1: Species directly neighboured to cupuaçu *(Theobroma grandiflorum)* in the four cultivation systems and spacing between and within the rows

cultivation system	neighbouring species within the row	spacing within the row	species of next row	spacing to next row
mixed system 1	Theobroma grandiflorum	6.4m	Carica papaya	2.5m
mixed system 2	Bertholletia excelsa	6.4m	Bixa orellana Bactris gasipaes	4m
mixed system 3	Schizolobium amazonicum	6.4m	Hevea brasiliensis Cocos nucifera	5m
monoculture	Theobroma grandiflorum	6.4m	Theobr. grandiflorum	7m

On the other hand, plant-plant interactions must be taken into consideration if analysing the effect of the different cultivation systems on the plants' development. In this context the still poorly understood below ground interactions including the role of the soil micro-organisms are attracting special interest (SCHROTH et al. 1995, SCHROTH 1996). Investigations on some species of the experimental site revealed that the quantitative and qualitative composition of micro-organisms in the rhizosphere can differ significantly from species to species (W. KRUSE, personal communication). Further experiments on this aspect are urgently needed.

b) factors being linked to the topography
Significant differences of the developmental state became evident considering the different blocks of the experimental site. Especially block E is marked by a very low percentage of adult trees after 3½ years cultivation. There are some indications that this phenomenon is connected with properties of the soil, although there is no significant gradient of the soil's nutrient content which would coincide with the observed tendency of plant development. In addition all plots are fertilised, a measure which should be capable to compensate the differences in nutrient availability. Thus, two aspects possibly explaining the gradient of soil fertility throughout the experimental site are taken into consideration: 1) significant differences of the soil's content of anti-nutrients or toxic elements (e.g. aluminium); 2) differences concerning the physical properties of the soil.

c) Differences between plants at the border and in the central part of the field
It could be observed that there is a tendency of advanced plant development at the border of the experimental site, while in the central part of the field most of the plants had not yet reached the adult stage. Two complexes of causes are taken into consideration: 1. influence of the primary or, respectively, secondary forest on the micro-climate and on the water balance of the soil of the directly adjacent cultivation area; 2. influence of the field's relief on the dispersal of nutrients and on the water supply. (In the interpolated middle the field represents a slight elevation.)

Irrespective of the fact, that the particular environmental factors which influenced the plant development need further investigations, the results of this study make evident, that cupuaçu plants react quite sensitive on site specific factors which apparently vary even slightly. The observations reveal that a rapid development and, thus, early productivity of cupuaçu plants is restricted to a narrow band of optima of environmental factors.
In some cases neighbouring cupuaçu plants reveal considerable developmental differences, even if the above mentioned factors of the culture conditions are identical (same block, same cropping system, same plot, same distance to the field's border). On the base of the data available it is not possible to elaborate whether these differences are mainly determined by genetic predisposition or by environmental factors, because most of the environmental factors causing the observed variability can also vary considerably in small spatial scales. Thus, the sensitive reaction of cupuaçu plants to site specific factors renders it problematical to assess the genetic predisposition of a single plant concerning its development and productivity. However, if the genetic background causes differences in development and production between some plants, at least three principles of a genetic effect must be considered: 1. differences of the breadth of the ecological amplitude concerning a limiting factor, 2. differences concerning the optimum of the ecological amplitude, and 3. differences in

physiological qualities more independent from environmental factors. In the latter case the observed quality will be influenced only quantitatively by site specific conditions. Genetic characters affecting the ecological amplitude can lead to even qualitative differences.

Thus, the simultaneous consideration of both the genetic predisposition and the effect of particular environmental conditions is suggested to be very important for the breeding of cupuaçu plants. This means that in practice selection and breeding of cupuaçu plants for high yield and rapid development require a detailed documentation of the environmental conditions, under which the quality determining characters had been observed.

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