# GROWTH REDUCTION EFFECTS OF PACLOBUTRAZOL APPLIED AT DIFFERENT CACAO SEEDLING STAGES[1]

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ABSTRACT - The effects of paclobutrazol on the morphological and growth characteristics of cacao (*Theobroma cacao* L.) seedlings were evaluated. The experiment was arranged in four randomized blocks in a split-plot lay-out. Main plots were assigned to growth stages (mature cotyledonary leaves, first, second and third flushes) and sub-plots to paclobutrazol dosages (0, 30, and 60 ppm). Periodic measurements were taken of stem diameter, height and leaf number. At the end of the experiment leaf area and dry weights of root, stem and leaves were obtained. In general, paclobutrazol decreased diameter, height, leaf number and leaf area in all concentrations. The effect depended on concentration and stage of growth. Dry weight of all plant parts decreased with the application of paclobutrazol. The highest root, stem and leaf dry weight reductions, 74%, 82% and 77%, respectively, were found at the 60 ppm-cotyledonary stage treatment. The lowest reduction was at the 60 ppm-third flush combination (22%, 38% and 39% for root, stem and leaf, respectively). There was more partitioning of assimilates to roots than to shoots in most of the treatment combinations.

Index terms: growth regulators, triazole, *Theobroma cacao*, assimilate partitioning.

## EFEITOS RETARDANTES DO PACLOBUTRAZOL APLICADO EM DIFERENTES ESTÁGIOS DE CRESCIMENTO DE PLÂNTULAS DE CACAU

RESUMO - Foram avaliados os efeitos do paclobutrazol na morfologia e crescimento de plântulas de cacau (*Theobroma cacao* L.). O experimento foi disposto em quatro blocos ao acaso num arranjo de parcelas subdivididas, com quatro repetições. Nas parcelas foram designados estágios de crescimento (folhas cotiledonares maduras, primeiro, segundo e terceiro lançamentos), e nas subparcelas, dosagens de paclobutrazol (0, 30 e 60 ppm). Foram realizadas mensurações periódicas do diâmetro, altura e número de folhas. No final do experimento, foram determinados a área foliar e os pesos secos da raiz, caule e folhas. A aplicação de paclobutrazol diminuiu o diâmetro, a altura, o número de folhas e a área foliar total das plântulas. O efeito dependeu da concentração e do estágio de crescimento. O peso seco de todas as partes da planta diminuiu com a aplicação de paclobutrazol. As maiores reduções nos pesos secos da raiz, caule e folhas (74%, 82% e 77%, respectivamente) foram encontradas na combinação 60 ppm-folhas cotiledonares. A menor redução foi no tratamento 60 ppm-terceiro lançamento (22%, 38% and 39% para raiz, caule e folhas, respectivamente). Houve mais partição de assimilados para a raiz do que para a parte aérea, na maioria das combinações.

Termos para indexação: reguladores de crescimento, triazoles, *Theobroma cacao*, partição de assimilados.

## INTRODUCTION

The experimental plant growth regulator paclobutrazol, ICI PP333, (2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H,1,2,4-triazol-1-yl)-pentan-3-ol), has been reported to inhibit gibberellic acid biosynthesis in plants (Goldsmith et al. 1983) by blocking the oxidation of kaurene to kaurenoic acid (Dalziel & Lawrence 1984, Goldsmith et al. 1983). This effect has been successfully used as a management strategy in annual crops. In water-logged rice (*Oryza sativa* L.) paclobutrazol was

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utilized to decrease height to avoid lodging. Paclobutrazol also increased rice yield in 2 of 3 years of experimental trials (Street et al. 1986). Application of paclobutrazol at a rate of 2.0 kg of a.i./ha at spikelet initiation stage completely prevented lodging of perennial ryegrass (*Lolium perenne* L. cv. S24). Paclobutrazol reduced stem internode length and strengthened the base of the stem. Total dry matter was also reduced but root dry matter accumulation increased at all rooting depths, therefore, changing the partitioning of photosynthates (Hampton & Hebblethwaite 1985).

Retardation of shoot growth and promotion of tuber growth of potato (*Solanum tuberosum* L. cv. Russet Burbank) plants by paclobutrazol has also been reported (Balamani & Poovaiah 1985). Tuber: shoot ratio in paclobutrazol-treated plants was 60% higher compared to control plants. Paclobutrazol also reduced leaf expansion and inhibited internode elongation which increased leaf shedding in sunflowers (*Helianthus annuus* L.). Fresh and dry weights of shoots were reduced proportionally to leaf area (Wample & Culver 1983). On strawberry (*Fragaria* x *ananassa* Duch.), paclobutrazol suppressed plant growth. Petioles, peduncles and pediceles were shortened with leaves and fruits tightly appressed to the crown. Runner suppression depended on time of application (Stang & Weis 1984). Paclobutrazol effects on stem elongation in beans (*Phaseolus vulgaris* L.) and in chrysanthemums (*Chrysanthemum morifolium* Ramat.) have also been obtained (Barrett & Bartuska 1982). Full potential of growth retardants may also be used in the turfgrass industry. Reduction of plant growth rate through its application should translate into substancial cost savings in terms of labor, fuel and machinary. Paclobutrazol tests in Kentucky bluegrass (*Poa pratensis* L.) showed that the photosynthate partitioning to the roots was changed. Probably, paclobutrazol indirectly influenced sink strength by reducing gibberellin levels thereby inhibiting cell division and elongation or altering sucrose metabolism (Hanson & Branham 1987).

Results of paclobutrazol effects on perennial crops have also been reported. On apple (*Malus domestica* Borkh.) paclobutrazol effects indicate potential for growth suppression which can reduce the pruning requirements (Quinlan 1982, Williams 1983). In 9-year-old clove [*Syzygium aromaticum* L. (Merr. & Perry)] trees, paclobutrazol reduced vegetative growth which resulted in a threefold increase in clove yield (Martin & Dabek 1988). Paclobutrazol has been reported to shorten the juvenile phase of rubber (*Hevea brasiliensis* Muell. Arg.) inducing precocious flowering. Those effects are a valuable aid in rubber breeding programs due to the simplicity of paclobutrazol application and its ability to retard growth which keeps the plant short. Short-statured plants facilitate pathogen control and hand pollination (Yeang & Samsuddin 1986).

In cacao (*Theobroma cacao* L.), the use of paclobutrazol on seedlings reduced growth and induced a premature development of jorquette on a number of paclobutrazol-treated plants. Flower formation was also observed in two of the jorquetted plants (Orchard 1984). Valle & Almeida (1989) also observed growth reductions as high as 32% with the application of 45 and 90 ppm of paclobutrazol. They reported that the 90 ppm treatment changed the partitioning of photosynthate, decreasing the shoot: root ratio which was significantly higher than that of the other treatments.

The objective of this work was to evaluate the growth reduction effects of paclobutrazol when applied at different cacao seedling stages.

## MATERIALS AND METHODS

The experiment was installed and conducted under semi-controlled conditions in a greenhouse of the Cacao Research Center (CEPEC) in Itabuna, Bahia, Brazil. Cacao seeds were hand-planted on July 31, 1986 in plastic bags filled with 10 kg of soil and arranged in four randomized blocks in a split-plot design. Main plots were assigned to growth stages, and subplots to dosages of paclobutrazol. The growth stages in which paclobutrazol was applied were: when the cotyledonary leaves reached full size and maturity, at the first flushing, at the second flushing, and at the third flushing. The dosages were 0, 30, and 60 ppm of paclobutrazol mixed in 2.0 L of water. Paclobutrazol was applied directly to the soil at 28, 67, 99, and 127 days after planting (DAP) which correspond to the beginning targeted growth stages, respectively. Measurements were taken on diameter, height and leaf number. At the end of the experimental period, 300 DAP and when the seedlings were jorquetting, the plants were collected, leaf number counted and dry weights of roots, stems and leaves obtained. Leaf area was measured with a photoelectric planimeter. Regression and test of means were performed utilizing the General Linear Model of the Statistical Analysis System package (1982).

**TABLE 1. Final mean diameter (DIAM, cm) height (cm), leaf area (LA, cm2) and leaf number (LN) for 'Catongo' cacao seedlings treated with two different dosages of PP333 applied at different growth stages.**

| Stage of application | Dosage | DIAM | Height | LA | LN |
|---|---|---|---|---|---|
| | -ppm- | ------ cm | ------ | -cm2- | |
| Cotyledonary | 30 | 2.03 a[1] | 140.7 a | 196.7 a | 72 a |
| | 60 | 1.34 b | 50.6 b | 60.5 b | 43 b |
| First flush | 30 | 1.76 b | 86.4 b | 117.6 b | 60 b |
| | 60 | 1.42 c | 54.8 c | 79.8 c | 49 c |
| Sec. flush | 30 | 1.51 b | 65.4 b | 88.7 b | 50 b |
| | 60 | 1.46 b | 46.0 c | 61.9 c | 53 b |
| Third flush | 30 | 1.60 c | 77.4 b | 99.4 c | 46 c |
| | 60 | 1.84 b | 62.1 c | 145.1 b | 68 b |
| Control | 0 | 2.06 a | 146.2 a | 206.6 a | 72 a |

[1] Means with the same letter in each column within stage of application are not significantly different from each other and from the control according to previously determined contrasts (P = 0.05).

## RESULTS AND DISCUSSION

### Diameter and height

Paclobutrazol influenced the diameter and height in all concentration and growth stages, except at the 30 ppm-cotyledonary stage application. The responses in this application were not significantly different from the control. However, the application of 60 ppm at the same stage, dramatically reduced these parameters (Table 1). This effect was more intense and clear with height which was decreased more than or closer to 60% within each stage than for diameter. Linear rates decreases of diameter and height showed that the effects of paclobutrazol were concentration and growth stage dependent and that they diminished with the age of the plant, that is, as the plants grew the effect of dosages tended to be lower. The plant height rate decrease reached its maximum depressing effect when paclobutrazol was applied at the second flushing in 30 and 60 ppm and decreased at the third flush stages (Tables 1 and 2). This effect was also noticeable with the diameter decrease rate which followed a similar pattern to the height. However, the diameter decrease rates were higher in the 60 ppm than in 30 ppm at the cotyledonary and first flush, were similar at the second flush in both dosages (Table 2), and the effect of 60 ppm at the third flush was less suppressing than 30 ppm, which was an unexpected result. At the end of the experimental period, plants with 60 ppm applied from the cotyledonary stage through the second flush maintained almost the same diameter and height (Table 1). Application of paclobutrazol at the third flush did not retard growth as much as the application at the other growth stages. With the 30 ppm dosage the growth retardation reached its minimum at the second flush.

### Leaf area and leaf number

The effect of paclobutrazol application on leaf area and leaf number was dramatic in most treatment combinations (Tables 1 and 2). In general, the decrease in both parameters was more pronounced with the application of 60 ppm than by the application of 30 ppm. The reduction in leaf area across stages of application and dosages ranged from 5% at the 30 ppm-cotyledonary stage, to approximately

70% at the 60 ppm-cotyledonary stage and 60 ppm-second flush treatments. Also, the leaf number reduction ranged from 40% at the 60 ppm-cotyledonary stage to 6% at the 60 ppm-third flushing. The 30 ppm-cotyledonary stage treatment was not significantly different from the control. Therefore, the results indicated that the reduction in cacao seedlings leaf area was not only due to the decrease in leaf number but also to the decrease of individual leaf area (Table 2). This reduction was due to an epinastic growth which produced a corrugated leaf. The individual leaf area reduction values ranged similarly with the total leaf area (Tables 1 and 2). Similar observations were reported by Adriensen (1985) in *Beloperone guttata* and in sunflower by Wample & Culver (1983).

Linear rates decreases of leaf number depended also of concentration and growth stage of paclobutrazol application and followed a similar pattern to height and diameter (Tables 1 and 2).

## Roots, stems, and leaf dry weight

All dry weights of the plant parts decreased with the application of paclobutrazol at the

**TABLE 2. Linear regression parameters for diameter (DIAM, cm), height (cm) and leaf number (LN) for 'Catongo' cacao seedlings treated with two different dosages of PP333 applied at different growth stages.**

| Stage of application | Dosage | Parameter | Intercept | Slope | r2 |
|---|---|---|---|---|---|
| | 30 | DIAM | 0.051 - 0.038 | 0.0066 - 0.0002 | 0.99 |
| Cotyledonary | 30 | Height | -15.26 - 4.98 | 0.509 - 0.027 | 0.97 |
| | 30 | LN | -9.93 - 2.41 | 0.260 - 0.013 | 0.97 |
| | 60 | DIAM | 0.185 - 0.028 | 0.0040 - 0.0001 | 0.98 |
| Cotyledonary | 60 | Height | 7.72 - 1.94 | 0.131 - 0.010 | 0.93 |
| | 60 | LN | -1.75 - 1.72 | 0.167 - 0.009 | 0.96 |
| | 30 | DIAM | 0.130 - 0.026 | 0.0054 - 0.0001 | 0.99 |
| First flush | 30 | Height | -0.24 - 3.37 | 0.277 - 0.018 | 0.95 |
| | 30 | LN | -7.05 - 1.45 | 0.255 - 0.008 | 0.98 |
| | 60 | DIAM | 0.182 - 0.025 | 0.0041 - 0.0001 | 0.99 |
| First flush | 60 | Height | 7.92 - 3.32 | 0.126 - 0.018 | 0.80 |
| | 60 | LN | -3.48 - 1.26 | 0.182 - 0.006 | 0.98 |
| | 30 | DIAM | 0.193 - 0.020 | 0.0045 - 0.0001 | 0.99 |
| Sec. flush | 30 | Height | 5.25 - 1.62 | 0.195 - 0.009 | 0.98 |
| | 30 | LN | -4.36 - 0.85 | 0.182 - 0.005 | 0.99 |
| | 60 | DIAM | 0.208 - 0.032 | 0.0040 - 0.0001 | 0.98 |
| Sec. flush | 60 | Height | 12.98 - 1.12 | 0.105 - 0.006 | 0.96 |
| | 60 | LN | -4.59 - 0.91 | 0.190 - 0.005 | 0.99 |
| | 30 | DIAM | 0.191 - 0.026 | 0.0049 - 0.0001 | 0.99 |
| Third flush | 30 | Height | 6.63 - 1.63 | 0.246 - 0.0009 | 0.98 |
| | 30 | LN | -1.80 - 0.93 | 0.166 - 0.005 | 0.99 |
| | 60 | DIAM | 0.134 - 0.030 | 0.0059 - 0.0001 | 0.99 |
| Third flush | 60 | Height | 13.57 - 3.16 | 0.185 - 0.017 | 0.90 |
| | 60 | LN | -8.21 - 1.76 | 0.250 - 0.009 | 0.98 |
| | | DIAM | 0.041 - 0.037 | 0.0068 - 0.0001 | 0.99 |
| Control | 0 | Height | -16.21 - 5.29 | 0.527 - 0.029 | 0.96 |
| | | LN | -10.06 - 2.35 | 0.263 - 0.013 | 0.97 |

different growth stages. The exception was stem and leaf dry weights for the 30 ppm-cotyledonary stage application (Table 3). The highest root, stem and leaf weight decreases, 74%, 82% and 77%, respectively, were obtained with the application of 60 ppm at the cotyledonary stage. However, comparable responses were shown with the application of 60 ppm at the first and second flush.

The lowest dry weight decreases for all plant parts, 22%, 38% and 39% for root, stem and leaf, respectively, were found at the 60 ppm-third flush application. As a consequence, the total dry weight decrease was less at this dosage-stage combination (36%) than at the 60 ppm-cotyledonary, -first and -second flush stages. The total dry weight decrease in these applications was, on the average, 77% with respect to the control plants (Table 3). Therefore, the data reveal a decreasing effect of paclobutrazol when applied at later stages of growth.

The decrease in total dry weight obtained with the application of 30 ppm at the first and third flush compared to the control treatment were, on the average, 47, 58 and 54% for roots, stems and leaves, respectively. However, the largest decrease at the 30 ppm dosage was found at the second flush. For this application, roots, stems, and leaves were 58%, 69% and 63% lower than the same control plant parts, respectively. The largest plant part decreases at the 30 ppm-second flush combination resulted in an overall 65% total dry weight decrease compared to the control treatment. The mean decrease of total dry weight obtained with the application of 30 ppm at the first and third flush was 55%.

The application of paclobutrazol changed the percentage dry matter distribution of cacao. On a percent basis, the root dry weight increased in all treatment combinations except the 30 ppm-cotyledonary stage application. There was also a noticeable decrease in stem dry matter distribution with the application of 60 ppm of paclobutrazol at the cotyledonary, first and second flush stages. The decreases in the other treatment combinations were less pronounced. The leaf dry weight percentages were similar in all combinations. Also, the shoot:root ratio was significantly lower than the control in all combinations except the

**TABLE 3. Final means of root, stems, leaves, and total dry weight and shoot: root ratio (S:R) of 'Catongo' cacao seedlings treated with two different dosages of PP333 applied at different growth stages.**

| Stage of application | Dosage | Roots | Stem | Leaf | Total | S:R |
|---|---|---|---|---|---|---|
| | -ppm- | ---------------- | g/plant | ---------------- | | |
| Cotyledonary | 30 | 30.4 b[1] | 86.3 a | 99.3 a | 216.0 b | 6.1 a |
| | 60 | 9.1 c | 17.2 b | 25.1 b | 51.4 c | 4.7 b |
| First flush | 30 | 18.4 b | 41.0 b | 53.7 b | 113.1 b | 5.2 b |
| | 60 | 10.9 c | 18.8 c | 33.2 c | 62.9 c | 4.8 c |
| Sec. flush | 30 | 14.7 b | 30.3 b | 39.7 b | 84.7 b | 4.8 b |
| | 60 | 11.7 b | 18.8 c | 28.2 c | 58.7 c | 4.0 c |
| Third flush | 30 | 18.1 c | 41.1 c | 45.1 c | 104.3 c | 4.8 b |
| | 60 | 27.0 b | 60.6 b | 65.1 b | 152.7 b | 4.8 b |
| Control | 0 | 34.7 a | 97.9 a | 107.1 a | 239.7 a | 5.9 a |

[1] Means with the same letter in each column within stage of application are not significantly different from each other and from the control according to previously determined contrasts (P=0.05).

30 ppm-cotyledonary stage application (Table 3). The lowest shoot:root ratio in those treatments indicates an induced change in partitioning of assimilates.

Therefore, the data show that the 30 ppm dosage applied at the second flush stage would give a short-statured, well conformed cacao plant. Strategies to use short plants have been already followed in annual crops as different as rice and strawberry. Rice breeders are developing short-stature rice cultivars to maximize yield and reduce lodging, however, tall varieties continue to be grown on land not suitable for the short cultivars. The use of paclobutrazol offers a mean of controlling height and thus decreasing the potential for lodging. Also, the current interest in high density, ribbon row or spaced plant systems in the strawberry culture as an alternative to conventional matted rows focuses on the need for plant runner control (Scheel 1982). Paclobutrazol offers potential for effective runner control and reduces the need for hand labor or repeated mechanical removal with associated high costs and possible plant injury.

Therefore, strategies to control height in perennials tree crops through the use of growth retardants, although somewhat different to the strategies used for annual crops, need to be investigated in order to facilitate the management of perennial tree plantations like cacao. The height of the cacao tree could be maintained short either by using growth retardants, pruning, shade management, budding, or induced by breeding techniques which will be best. However, with the exception of selection of short plants by breeding, economic and management factors would determine the use of the other strategies to mantain the plants short-statured. It would be of great advantage to mantain the height of cacao short since this will facilitate harvesting and disease and pest control The data presented here show that it may be possible to obtain a short-statured, well-conformed cacao plant with the continuous use of paclobutrazol. Short plants may be used to increase the population density of commercial areas which would decrease yield per plant but should increase yield per area. These plants could be maintained short either by the use of growth retardants, pruning, or shade management.

## CONCLUSIONS

1. Cacao seedlings were sensible to paclobutrazol application for all the studied growth parameters. The greatest decrease response was obtained for height.

2. There was an interaction dosage: stage of growth. With the dosages tested, the best responses in terms of height decrease was found with the application of 60 ppm at the second flush. The effects of paclobutrazol decreased as the age of the plant increased.

3. The partitioning of assimilates was changed in favor to roots with the application of paclobutrazol in both dosages and most growth stages tested.

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