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THE EFFECT OF PRUNING ON PHOTOSYNTHETIC RATE OF CACAO TREES IN A NOVEL CROPPING SYSTEM

R.A.Susanti[,3)], P.Hadley[1)], A.Daymond[1)], P.Bastide[2)], S.Lambert[3)], K.Ingram[3)], J.C. Motamayor[3)]

1) School of Agriculture, Policy and Development, University of Reading, Earley Gate, Reading RG6 6AR, United Kingdom. Contact email: r.a.susanti@pgr.reading.ac.uk
2) CIRAD, Avenue Agropolis, 34398 Montpellier Cedex 5 France
3) Mars Cocoa Research Station Tarengge, Madani Village Wotu East Luwu South Sulawesi Indonesia 92971

ABSTRACT

An intensive growing system for cacao requires regular pruning to maintain canopy architecture. Frequent pruning has been recommended on cacao plantations to increase productivity but little research has been carried out to quantify the effect of such pruning on the physiological determinants of yield in cacao and photosynthesis in particular. In this study, the impact of pruning on photosynthesis was measured over three years, in trees of cacao clone (M01) maintained with one to four branches and either in trellis or conventional growing system. The impact of pruning and leaf age on photosynthetic rate was also investigated over one year where trees of two cacao clones (M01 and 45) were maintained in trellis system growing in an East-West orientation and a planting density of 2000 trees ha^{-1}.

Pruning increased light-saturated photosynthetic rate by 13.1-35.7%. In addition, mid-aged leaves had a higher photosynthetic rate compared with young and old leaves. No differences in photosynthetic rate were observed between the two clones.

Pruning increases canopy light transmission and light availability for interior leaves, therefore, increasing leaf photosynthetic rate. Photosynthetic rate may also be increased through an increase in the demand for carbohydrate by the pruned tree. By removing photosynthetically less efficient older leaves, pruning also improves the overall photosynthetic efficiency of the canopy and stimulates the tree to produce new growth.

Keywords: *Cacao, Pruning, Photosynthesis, Trellis*

INTRODUCTION

Theobroma cacao is a diploid tree species which is believed to have its origins in the Upper Amazon rainforests of South America (Motamayor et al., 2002). Cacao was first domesticated approximately 3,000 years ago in Central America (Argout et al., 2011) and is now grown throughout humid tropical regions in West Africa, Central and South America, and South East Asia. Cacao is grown as a cash crop and is an important export commodity for a number of producing countries. Cocoa beans are used in the manufacture of chocolate and are also used in the production of cosmetics (Hebbar et al., 2011).

One way to increase cocoa production, to fulfil cocoa increasing demand, is to adopt more intensive production techniques. In this study, the impact of an intensive growing system utilizing a trellis to maximize light interception and yield was examined. This system requires regular pruning to maintain canopy architecture. Although the effect of pruning has been studied in other crops, such as apple (Li, 2001) and coffee (Morais et al., 2012), very limited literature exists for cacao. This study, therefore, aimed to test the hypothesis that pruning will increase cacao leaf photosynthetic rate, as a yield determinant, and that this benefit is cost-effective.

MATERIALS AND METHODS

Field experiments were located at the Mars Cocoa Research Station (CRS) in Tarengge, Madani Village, East Luwu, South Sulawesi, Indonesia. The research station is located at 120°47′48″ E s/d 120°48′24″E and 02°33′06″ S s/d 02°33′33″ S. Two experimental trials were conducted: “Biomass 1” (monoclonal) and “Biomass 2” (two clones).

BIOMASS 1 TRIAL

Before planting in the field, plants of clone M01 were initially raised under nursery conditions for 3 months after grafting on 3 month-old rootstocks. Trees were planted in February 2012 in rows at a spacing of 625, 816, 833, and 1111 trees ha^{-1} in an East to West direction.

In April 2014, the trees were shaped to give a defined architecture (“pruning regime treatments”). Two designs were tested; trees were either arranged on single plane in a trellis system and pruned such that they had one, two, three or four main branches per tree; or trees were managed in a conventional way (non-trellis system) with two to four branches per tree. Pruning was conducted on a regular basis, four times per year (January, April, July, October), approximately six weeks after leaf flushing. Tree canopy height was always kept below 2.5 meters. The Biomass 1 trial was fertigated from the beginning of 2015. Fertigation using drip irrigation system was given to the trees in the trial two times a day, to make sure that the trees get enough nutrient for growth.

Photosynthetic and transpiration rates were measured, using an Infra-Red Gas Analyzer (LC-Pro-SD, ADC Bioscientific, Hoddesdon, UK). Measurements were made to coincide with pruning sessions from January 2015 until October 2017. For each pruning event, a set of measurements were made before pruning was conducted, and then repeated 1-4 days after pruning. Measurements were made between 6.30-10.30 am; the 3rd, 4th or 5th healthy sun-exposed leaves from a given branch were chosen for measurement. In total, 12 sets (before and after pruning) of photosynthetic measurement were carried out. The equipment was operated at a chamber temperature of 27°C and the light attachment was set to provide 900 µmol m^{-2} s^{-1}, which is saturating for cacao.

BIOMASS 2 TRIAL

In contrast to the Biomass 1 trial, where the trellis system was installed sometime after planting, the Biomass 2 trial was planted directly onto a trellis system. The vertical and lateral branches of all the trees were trained onto the trellis. Two clones (M01 and 45) were planted in November 2014 1.6 meters apart in rows 3 meters apart (after 3 months growth under nursery conditions after grafting on 3 month-old rootstocks), in an East-West orientation giving a planting density of 2000 trees ha^{-1}. All trees had three branches. M01 and 45 were self-incompatible clones but cross-compatible between each other.

The experiment consisted of six plots arranged in a randomised block design between clones (three plots per clone, each plot with six rows and eight trees per row). Within each of these, double row plots were adjacent to one another and single row plots were adjacent to one another. Planting densities and orientation blocks were not randomized. East-West and North-South orientation treatments were separated, as were planting density treatments: 2000 trees.ha^{-1}, 3300 trees.ha^{-1}, and 5000 trees.ha^{-1}.

As for the biomass 1 trial, pruning was conducted on a regular basis, four times per year (January, April, July, October), approximately six weeks after leaf flushing. Tree canopy height was always kept below 2.75 meters; and inter-twined lateral branches were cut to leave bigger, stronger, and healthier lateral branches. The first photosynthetic measurement was conducted in February 2017 to coincide with a pruning event, followed by further measurements at three month intervals to coincide with pruning events in May and October 2017 giving 3 sets (before and after pruning) of photosynthetic measurements. The trial was fertigated with the same system as in Biomass 1 trial.

As with the Biomass 1 trial, a set of photosynthetic measurements were made before pruning was conducted, and then repeated 1-7 days after pruning for each pruning event. Two sampled trees were taken for each plot for photosynthetic measurements (six trees in total), measured at three different heights: below 1 meter, between 1-2 meter, and above 2 meters. For each height, leaves of three different ages were sampled: “young”, “middle-aged”, and “old” leaves.

STATISTICAL ANALYSIS

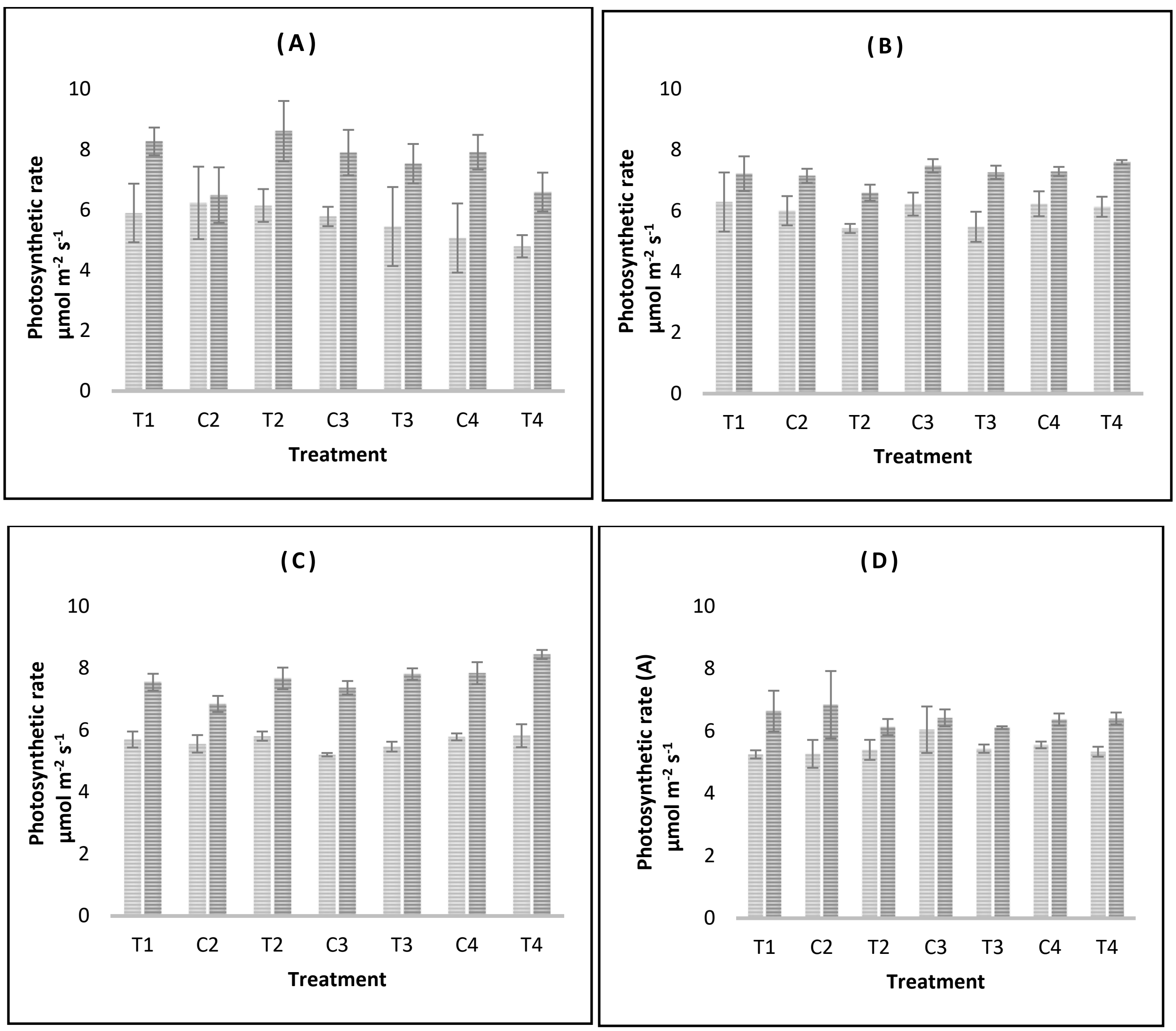
Statistical analysis was carried out using GenStat 18th edition software (VSN International Ltd., Hemel Hempstead, UK). For each trial, general analysis of variance (ANOVA) was used to assess the effect of different clones, time (before and after pruning), measurement height, leaf age, and also the interaction between the factors, on photosynthetic and transpiration rates.

RESULT

BIOMASS 1

T1 : 1 branch+trellis | C2: 2 branches | T2 : 2 branches +trellis | C3 : 3 branches | T3 : 3 branches + trellis | C4 : 4 branches | T4 : 4 branches + trellis

Figure 1: Photosynthetic rate subjected to seven different pruning regimes in the Biomass 1 trial before and after pruning, measured in A. March 2015, B. February 2017, C. May 2017, and D. October 2017. Values are means across four replicates (+/- standard errors).



Legend: Before Pruning After Pruning

Photosynthetic rate was significantly (P< 0.001) higher after each pruning (Figure 1) (the average rates before pruning and after pruning were 5.63 μmol m^{-2} s^{-1} and 7.62 μmol m^{-2} s^{-1} in March 2015; 5.97 μmol m^{-2} s^{-1} and 7.23 μmol m^{-2} s^{-1} in February 2017; 5.58 μmol m^{-2} s^{-1} and 7.62 μmol m^{-2} s^{-1} in May 2017; 5.47 μmol m^{-2} s^{-1} and 6.41 μmol m^{-2} s^{-1} in October 2017). There was no significant effect of different pruning regimes/branch architecture on each occasion (Note that two trees died in 2016 and one off-type tree was found and so these were excluded from the analysis).

BIOMASS 2

The photosynthetic rate was significantly (P<0.001) higher after each pruning (average before the February-March 2017 pruning was 4.67 μmol m^{-2} s^{-1} and 6.14 μmol m^{-2} s^{-1} after pruning; average before the May 2017 pruning was 4.88 μmol m^{-2} s^{-1} and 5.85 μmol m^{-2} s^{-1} after pruning, and 4.28 μmol m^{-2} s^{-1} compared with 5.14 μmol m^{-2} s^{-1} after pruning in October) (Figure 2). The photosynthetic rate of the middle age leaves was also significantly (P<0.001) higher than the older and younger leaves (average for middle age was 6.38 μmol m^{-2} s^{-1} compared with 5.03 μmol m^{-2} s^{-1} and 4.81 μmol m^{-2} s^{-1} for old and young leaves, respectively, in February 2017; 7.16 μmol m^{-2} s^{-1} compared with 4.67 μmol m^{-2} s^{-1} and 4.29 μmol m^{-2} s^{-1} for old and young leaves in May 2017; and 6.22 μmol m^{-2} s^{-1} compared with 3.87 μmol m^{-2} s^{-1} and 4.03 μmol m^{-2} s^{-1} for old and young leaves, respectively in October 2017 (Figure 2). There were no significant differences between the photosynthetic rates of the two clones (P=0.287) or between leaves from different heights (P=0.631) or any significant interactions between factors.

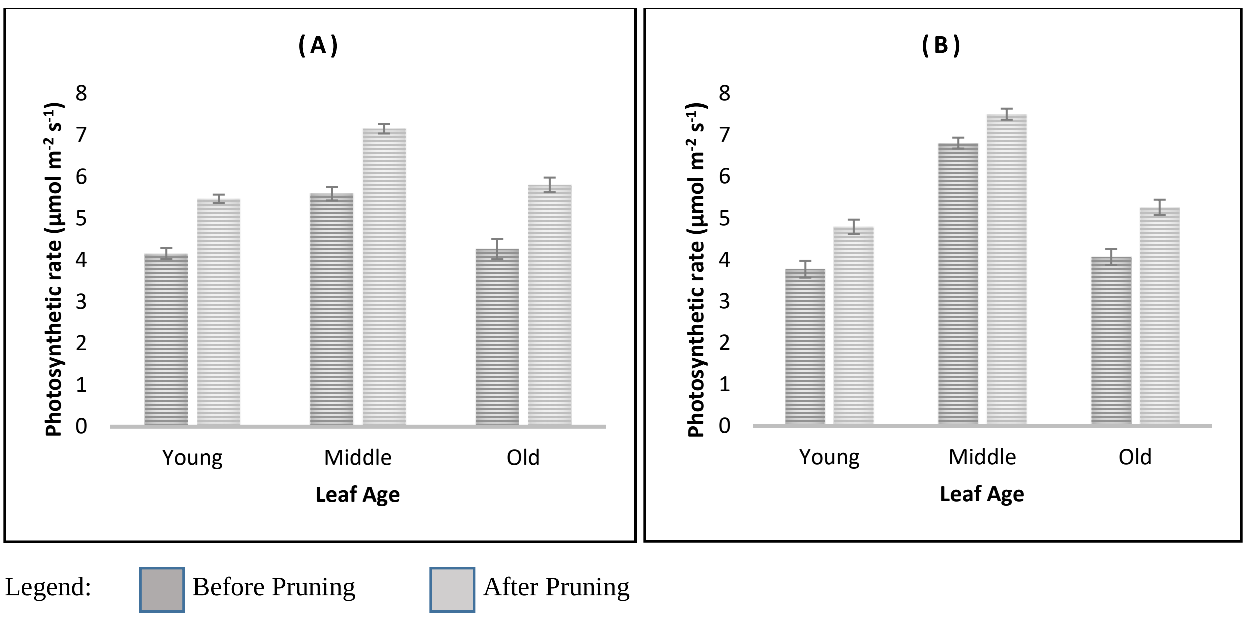


Figure 2: Photosynthetic rate of three different leaf ages in the Biomass 2 trial before and after pruning, measured in (A) February-March 2017 (B) May 2017. Values are means across three plots as replicates, two clones, and three canopy heights (+/- standard errors)

However, significant differences in photosynthetic rate were observed between canopy heights in October 2017 (P=0.002). Photosynthetic rates were highest in leaves above 2 m (5.01 μmol m^{-2} s^{-1}) compared to trees in below 1 m (4.23 μmol m^{-2} s^{-1}) or between 1-2m high (4.38 μmol m^{-2} s^{-1}) (Figure 3)

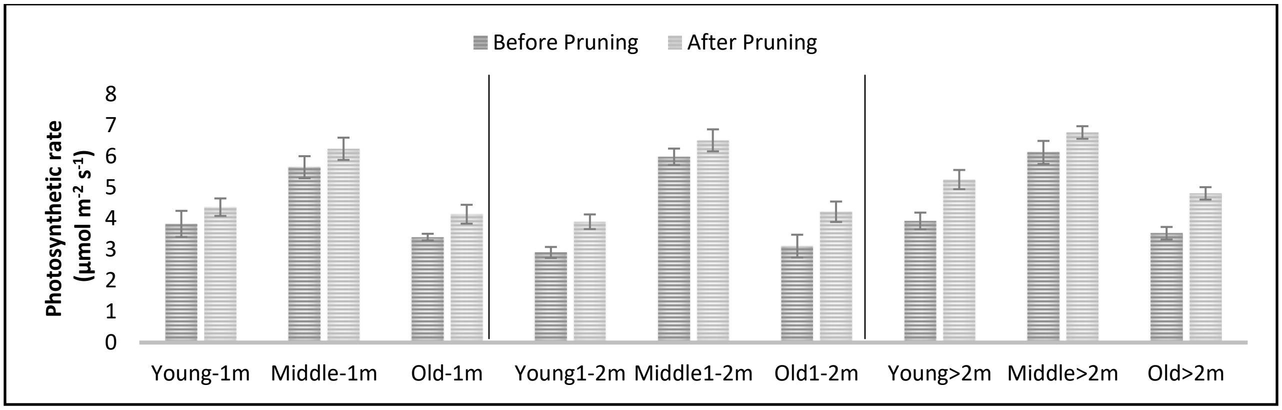


Figure 3: Photosynthetic rate of three different leaf ages (Young, Middle, Old) and three different canopy heights (Below 1meter, Between 1-2meter, Above 2meter) in the Biomass 2 trial before and after pruning, measured in October 2017. Values are means across two plots as replicates and two clones

DISCUSSION

Here, it was shown that the light-saturated photosynthetic rate of leaves was significantly higher after pruning, in both trials. A possible explanation for this increase in photosynthetic rate is that pruning stimulates new leaf growth, thereby altering the source-sink ratio. The results suggest that cacao might be able to increase its assimilation rate in response to demand for carbohydrate by stimulated leaf growth. This phenomenon of increasing photosynthetic rate after pruning also was observed in other crops, such as apple (Li, 2001) and grapes (Hunter et al., 1988), but not in coffee (Morais et al., 2012).

In the Biomass 2 trial, the middle-aged leaves had higher photosynthetic rates than younger and older leaves. Previous studies on cocoa have demonstrated the higher photosynthetic capacity of younger leaves vs older leaves (Baker and Hardwick, 1973; Machado and Hardwick, 1988). In the present study, young leaves had lower photosynthetic rates than middle-aged leaves. Photosynthetic capacity and chlorophyll content increase in parallel with leaf development (Baker and Hardwick, 1973), but maximum chlorophyll synthesis and maximum chloroplast development does not occur until the leaf expansion is completed (Baker et al., 1975). This phenomenon explains the lower photosynthetic rate observed here in young leaves since they were not fully expanded and therefore chloroplast development may not have been complete. Similar behaviour in different leaf ages affecting photosynthesis rate also was found in maple and oak trees (Reich et al., 1991).

From one year measurements in the Biomass 2 trial, no differences in photosynthetic rate were observed between the cacao clones M01 and 45, however, differences in photosynthetic rates have been observed previously between other cacao clones (Daymond et al., 2011).

To conclude net leaf photosynthesis was significantly higher after pruning events in both of the trials studied here. Pruning increased photosynthetic rate by 15.9-35.5% in Biomass 1 trial and 13.1-35.7% in Biomass 2. The implication of this is that frequent pruning is important to increase tree productivity since it has the effect of stimulating new flush leaf growth and increasing photosynthetic rates of the remainder of the canopy. The increased photosynthetic rates after pruning suggest that cacao leaves have an intrinsic capacity to respond to increased assimilate demand. Pruning also reduces total leaf area such that assimilation increases the remaining leaves to meet assimilate demand for pod growth.

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