

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

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### ABSTRACT

An intensive growing system requires regular pruning to maintain canopy architecture. More frequent pruning times on cacao plantations have been recommended to increase the productivity. However, limited studies have examined this topic in cacao. In this study, the impact of pruning on canopy photosynthesis was observed at different times of the year (January, April, July, October) over three years period, for one cacao clone (M01) with different number of branches (one, two, three, and four), and different growing systems (trellis application and non-trellis). The impact of pruning and leaf age was also investigated over one year period, for two cacao clones (M01 and 45) in a trellis system growing in an East-West orientation and a planting density of 2000 trees ha<sup>-1</sup>.

Overall, net photosynthesis was affected by the pruning treatments. In addition, leaf age also affects leaf photosynthetic rate. These results suggest that frequent pruning time is important to increase tree productivity.

Keywords: *Cacao, Pruning, Photosynthesis, Trellis*

### INTRODUCTION

*Theobroma cacao* is a diploid tree species which is native to the rainforests of South America. It is believed to have its origins in the Upper Amazon (Motamayor et al., 2002). Cacao was first domesticated approximately 3,000 years ago in Central America (Argout, 2011) and is now grown in tropical regions in West Africa, Central and South America, and Asia.

Cocoa is grown as a cash crop and is an important export commodity for a number of producing countries. It is also a key commodity which is imported by consuming countries, which typically do not have suitable climates for cocoa production. Cocoa beans are used in the manufacture of chocolate, which is a large and expanding market in Europe, America, and Asia. Cocoa is also used in the production of cosmetics (Hebbar et al., 2011).

Whilst demand for cocoa continues to increase, on current trends, production is unlikely to keep pace, so that by 2020 it is predicted that world cocoa production could be 1 million tonnes lower than demand (ICCO, 2014). One way to increase cocoa production is to adopt more intensive production techniques. In this study, the impact of intensive growing system in trellis to maximize light interception and yield were observed. This system requires regular pruning to maintain canopy architecture. Although pruning effect has been studied in crops, such as apple (Li, 2001) and coffee (Morais, 2012), very limited literature for cacao exists. This study examines the impact of pruning on cacao canopy photosynthesis.

### MATERIALS AND METHOD

Field experiments were located at the Mars Cocoa Research Station (CRS) in Tarengge Village, East Luwu, South Sulawesi, Indonesia. Experiments were conducted in two trials: "Biomass 1" (monoclonal) and "Biomass 2" (two clones).

## BIOMASS 1 TRIAL

The Biomass 1 trial was planted with the M01 clone, growing in an East to West direction. It was planted on 18 February 2012. Before being planted, plants were grown in the nursery for 6 months: 3 months for the rootstock to grow enough for grafting and 3 months after grafting.

In April 2014, the trees were shaped to give a defined architecture (“pruning regime treatments”). Two designs were tested. First, trees are arranged on a single plane on a trellis system and pruned such that they had one, two, three or four main branches. Secondly, trees were managed in a conventional way (non-trellis system) as farmers usually do and pruned to have a range of branches (two to four branches), thereby giving seven pruning treatments: one branch+trellis, two branches, two branches+trellis, three branches, three branches+trellis, four branches, and four branches+trellis. 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 m. The Biomass 1 trial was fertigated since the beginning of 2015.

Photosynthetic rates and stomatal conductance were measured, using an Infra-Red Gas Analyzer (LC-Pro-SD, ADC Bioscientific, Hoddesdon, UK). Measurements were made in the Biomass 1 trial to coincide with prunings from January 2015 until October 2017 and were made between 6.30-10.30 am. In total, 12 sets (before and after pruning) of photosynthetic measurement were made. The 3rd, 4th or 5th healthy sun-exposed leaves were chosen for the measurements. Four replicate trees were sampled trees from the seven pruning treatments. Initial training in the use of the equipment was conducted on 4-15 August 2014 at the University of Reading, UK. A preliminary trial, to determine equipment settings, was conducted from 6-7 September 2014. Equipment was operated at a chamber temperature of 27°C and the light attachment was set to 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$ . This value was chosen as optimum condition for photosynthetic rate, based on light and temperature response curve conducted previously.

Statistical analysis was carried out using GenStat 16<sup>th</sup> edition software (VSN International Ltd., Hemel Hempstead, UK). For each trial, general analysis of variance (ANOVA) was used to assess the effect of different pruning regime treatments, densities, time, and also the interaction between the factors, for all gas exchange parameters (photosynthetic rate, transpiration rate, and stomatal water vapour conductance).

## BIOMASS 2 TRIAL

In contrast to the Biomass 1 trial where a trellis system was installed sometime after planting, the Biomass 2 trial was planted directly onto a trellis system. Vertical and lateral branches from all the trees were trained onto the trellis system. Two clones (M01 and 45) were planted in November 2014 (after 6 months growth under nursery conditions), in an East-West orientation and 2000 trees  $\text{ha}^{-1}$  planting density. The trees had three branches. M01 has an I/O allele combination and 45 has I/33, which made them as self-incompatible clones. Both are cross-compatible between each other.

The sampled field consisted of six plots (each plot had six rows, and each row had eight trees) arranged in a randomised block design. The planting density of 2000 trees  $\text{ha}^{-1}$  had a single trellis system, the distance between each tree is 1.6 m, and the distance between rows for all densities was 3 m.

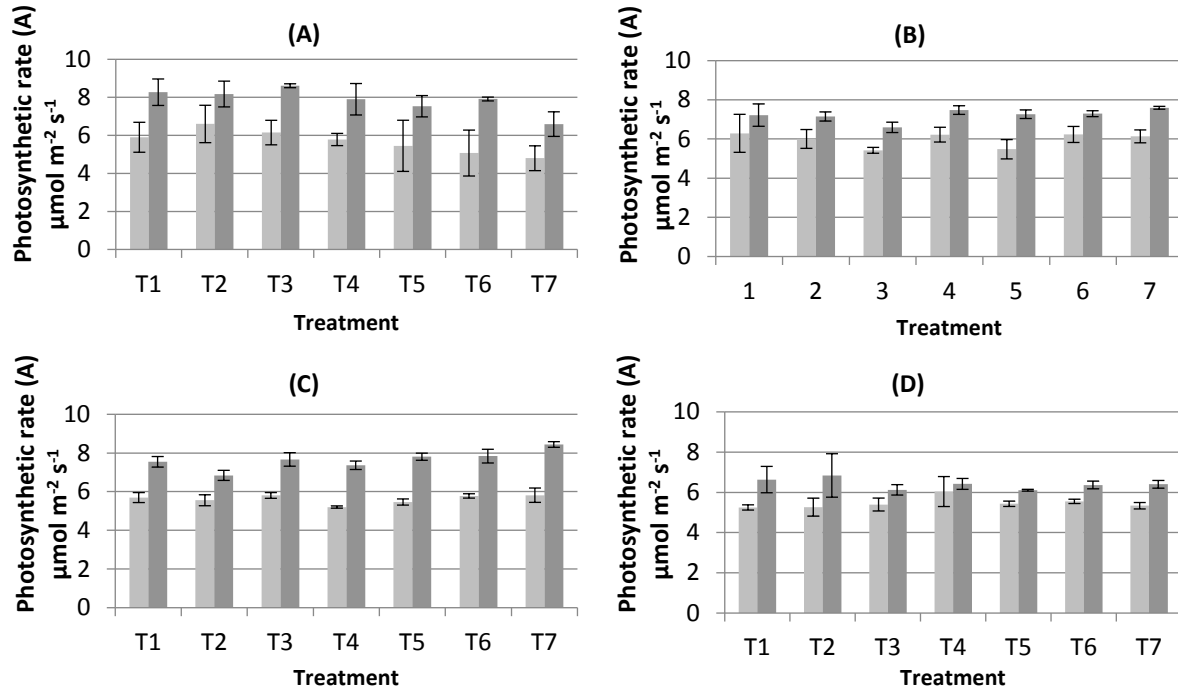
As for the biomass 1 trial, pruning was conducted on a regular basis, four times per year (January, April, July, October), approximately six weeks after leaf flushing. Tree canopy height was always kept below 2.75 m; and inter-twined lateral branches were cut to leave bigger, stronger, and healthier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

Two sampled trees were taken from each plot for photosynthetic measurements, measured at three different heights: below 1m, between 1-2m, and above 2m. For each height leaves of three different age were sampled: young, middle-aged, and old leaf. Measurements were between 6.30-10.30 am. In total, 3 sets (before and after pruning) of photosynthetic measurement were made. Equipment was operated at a chamber temperature of 27°C and the light attachment was set to 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$ .

Statistical analysis was carried out using GenStat 16<sup>th</sup> 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, measurement height, leaf age and also interaction between the factors, on photosynthetic rate and transpiration rate.

## RESULT

### BIOMASS 1



Legend :  Before Pruning  After Pruning

T1 : 1 branch+trellis | T2: 2 branches | T3 : 2 branches +trellis | T4 : 3 branches | T5 : 3 branches + trellis | T6 : 4 branches | T7 : 4 branches + trellis

Figure 1: Photosynthetic rate of trees 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).

Significant differences between treatments were only detected in March 2015 (first measurement), February 2017, May 2017, and October 2017 (last measurement) (Figure 1). On each occasion there was a significant effect of pruning ( $P < 0.001$ ) such that photosynthetic rate was higher after pruning (the average rates before pruning and after pruning were  $5.63 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $7.62 \mu\text{mol m}^{-2} \text{s}^{-1}$  in March 2015;  $5.97 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $7.23 \mu\text{mol m}^{-2} \text{s}^{-1}$  in February 2017;  $5.58 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $7.62 \mu\text{mol m}^{-2} \text{s}^{-1}$  in May 2017;  $5.47 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $6.41 \mu\text{mol m}^{-2} \text{s}^{-1}$  in October 2017). There was no significant effect of different pruning regimes/branch architecture on each occasion (Note that two trees died in 2016 (Tree 1 (1 branch + trellis pruning regime) in each planting density 625 and 833 trees  $\text{ha}^{-1}$ ), and off-type tree was found in the two branches+trellis treatment, so were excluded from the analysis).

### BIOMASS 2

In February-March 2017, significant differences in average photosynthetic rate were detected between before and after pruning ( $P < 0.001$ ), and also between leaf ages (young, middle, old) ( $P < 0.001$ ). The photosynthetic rate was higher after pruning (average before pruning was  $4.67 \mu\text{mol m}^{-2} \text{s}^{-1}$  compared with  $6.14 \mu\text{mol m}^{-2} \text{s}^{-1}$  after pruning). Photosynthetic rate of the middle age leaves was higher than the other age categories (average for middle age was  $6.38 \mu\text{mol m}^{-2} \text{s}^{-1}$  compared with  $5.03 \mu\text{mol m}^{-2} \text{s}^{-1}$  and  $4.81 \mu\text{mol m}^{-2} \text{s}^{-1}$  for old and young leaves, respectively). There

were no significant differences between the two clones ( $P=0.287$ ) or between leaves from different heights ( $P=0.631$ ) nor any significant interactions between factors. No significant effects of leaf age ( $P=0.382$ ), height ( $P=0.949$ ), pruning ( $P=0.252$ ), or clone ( $P=0.374$ ) were observed on transpiration rate (E).

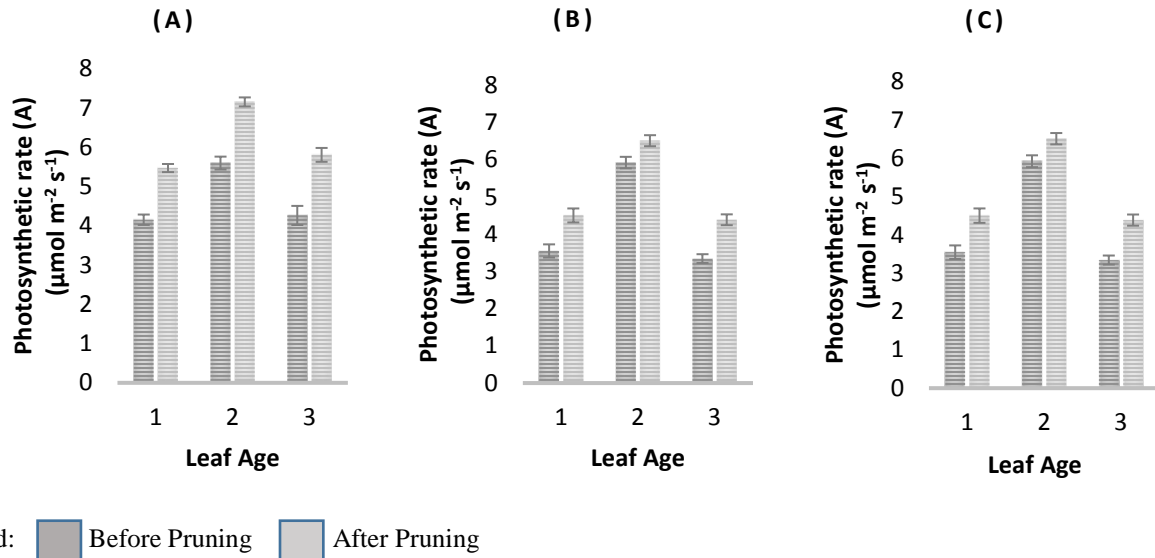


Figure 2: Photosynthetic rate of trees of three different leaf ages in the Biomass 2 trial before and after pruning, measured in (a) February-March 2017 (b) May 2017 and (c) October 2017. Values are means across three plots as replicates, two clones, and three canopy heights (+/- standard errors)

Similar results were observed in the second set of measurements before and after pruning in May-June 2017 and October 2017, where again significant differences in photosynthetic rate were detected between before and after pruning ( $P<0.001$ ) and also between leaf ages (young, middle, old) ( $P<0.001$ ), as could be seen in Figure 2. The photosynthetic rate was higher after pruning (average before pruning was  $4.88 \mu\text{mol m}^{-2} \text{s}^{-1}$  compared with  $5.85 \mu\text{mol m}^{-2} \text{s}^{-1}$  after pruning in May 2017, and  $4.28 \mu\text{mol m}^{-2} \text{s}^{-1}$  compared with  $5.14 \mu\text{mol m}^{-2} \text{s}^{-1}$  after pruning). Photosynthetic rate of the middle age leaves was higher than the other age categories (average for middle age was  $7.16 \mu\text{mol m}^{-2} \text{s}^{-1}$  compared with old  $4.67 \mu\text{mol m}^{-2} \text{s}^{-1}$  and young  $4.28 \mu\text{mol m}^{-2} \text{s}^{-1}$  in May 2017, and the average for middle-aged leaf was  $6.51$  compared with  $4.39$  old and  $4.51$  young  $\mu\text{mol m}^{-2} \text{s}^{-1}$ ). There was no significant difference between the two clones ( $P=0.168$  in May 2017;  $P=0.232$  in October 2017), between leaves from different heights in May 2017 ( $P=0.224$ ), or any significant interactions between factors. However, height was found as a significant factor for photosynthetic rate in October 2017 ( $P=0.002$ ).

In the May-June measurements, additionally, significant differences were observed between different canopy heights for transpiration rate (E) ( $P<0.001$ ), as could be seen in Figure 3. Transpiration rate at a height above 2 m was higher than at other heights (average for above 2 m was  $1.56 \text{ mmol m}^{-2} \text{s}^{-1}$  compared with  $1.15 \text{ mmol m}^{-2} \text{s}^{-1}$  in 1 m and between 1-2 m  $1.18 \text{ mmol m}^{-2} \text{s}^{-1}$ ). However, no significant difference in transpiration rate was observed either in February or October 2017.

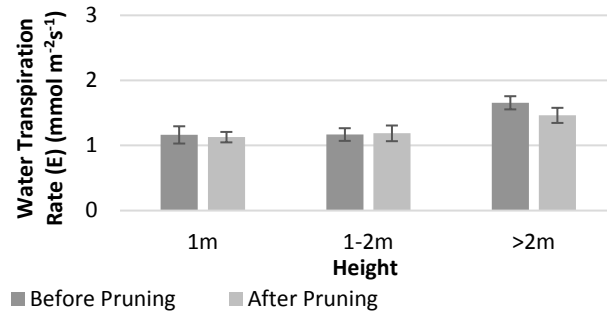


Figure 3: Transpiration rate of trees of three different height in the Biomass 2 trial before and after pruning, measured in May 2017. Values are means across three plots as replicates, two clones, and three leaf age (+/- standard errors)

## DISCUSSION

The trials described here are to determine how to maximise light interception and yield through pruning and training of the canopy. Previous research on cacao (Thomas and Balasimha, 1992) has shown that interception of Photosynthetically Active Radiation (PAR) was increased through pruning. Furthermore, the photosynthetic rate was significantly higher after pruning, both in the Biomass 1 (since March 2015 until October 2017) and Biomass 2 (February 2017 until October 2017) trial. A hypothesis to explain this increase in photosynthetic rate is that pruning stimulates new growth production, thereby altering the source-sink ratio.

In the Biomass 2 trial, the middle-aged leaves had higher photosynthetic rates than young and old ones (preliminary data). Previous studies have demonstrated the higher photosynthetic capacity of younger leaves vs older leaves (Baker and Hardwick, 1973; Machado and Hardwick, 1988). The abundance of photosynthetically inefficient older leaves results in a poor bean weight/overall biomass ratio (Bastide, 2003). Photosynthetic capacity and chlorophyll content increase in parallel with leaf development (Baker & Hardwick, 1973), but maximum chlorophyll synthesis and maximum chloroplast development do not occur until the leaf expansion is completed (Baker et al., 1975). The absence of green colour in very young leaves is because the chloroplasts are initially small and few rather than due to a delay in chloroplast development.

Leaf age and pruning treatment were proven in two trials (Biomass 1 and Biomass 2) as significant factors for higher photosynthetic rate. After pruning and middle-aged leaf gave the highest photosynthetic rate, compare to before pruning or young-old leaves. While number of branches or trellis/non-trellis system doesn't give any significant effect. Higher transpiration rate was observed in above 2m in May 2017 measurement, due to high rainfall intensity during the period. To date, a significant difference of photosynthetic rate between genotypes or leaves from different heights has not been seen (preliminary data).

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