University of Technology Sydney

The Environmental Constraints on Cocoa (*Theobroma cacao*) Production in north Australia

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Disclaimer

I, Nathan Leibel hereby declare that the work in this thesis is that of the candidate alone, except where indicated in the text, and as described below.

Chapter 5: The cocoa fat melting profile for Mossman, Queensland beans was collected by Queensland Department of Primary Industries and analysed by McRoberstons bean processing factory in Singapore and owned by Cadbury Schweppes.

Chapter 6: Stem diameters for each Northern Australia Cocoa Development Alliance experiment site were collected by the Department of Primary Industries in each of the States and Territory.

Air temperature data for the Broome experimental site shown in Appendix 13 was collected by the Western Australian Department of Agriculture.

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Nathan Leibel

Abstract

This thesis describes the research undertaken to determine whether cocoa (*Theobroma cacao*) could be successfully produced in north Australia. Initial observations indicated that high solar radiation, high leaf-to-air vapour pressure differences (LAVPD) and cold over-night chilling temperatures would be the most significant environmental parameters affecting the performance of cocoa in north Australia.

Experiments were carried out to assess the impact of supra-optimal and sub-optimal climatic conditions on cocoa performance using (1) cocoa seedlings established under solar irradiance ranging from 25 to 70% transmitted light; and (2) previously established cocoa to assess leaf photosynthetic performance, leaf chlorophyll fluorescence, leaf attributes, stem growth and yield quality and quantity under field conditions. Specific areas of study included:

<u>The effect of different shade treatments on cocoa establishment</u>

Cocoa seedlings subject to irradiance levels of 25 to 70% transmitted light showed no significant differences in relative growth rates. However, at 70% treatment canopies were smaller compared to the three lower light treatments. Differences in total canopy area were attributed to photoinhibition and results are discussed with reference to leaf carotenoid concentrations and leaf longevity.

<u>The effect of different shade treatments and environmental variables on leaf performance</u>

Maximum photosynthetic rates in the field ranged from approximately 1 to 9 μmol m^{-2} s^{-1}. Differences in light saturated photosynthesis were attributed to differing shade treatments, changes in LAVPD (0.3 to 4.9 kPa), low and high leaf temperatures (8 to 42 ^{0}C), dynamic photoinhibition ($\Delta F/F_m'$ 0.2 to 0.7), leaf nitrogen content (1.7 to 2.4 %) and SLA (15 to 26 m^2 kg^{-1}).

<u>The impact of cold over-night temperatures</u>

Over-night chilling air temperatures of <10 ^{0}C were shown to cause substantial reductions in the number of open photosystem II reaction centers ($\Delta F/F_m'$) the following morning irrespective of shade treatment. Reductions in $\Delta F/F_m'$ were associated with extremely low rates of leaf carbon assimilation which was attributed to sub-optimal leaf thermodynamics and photosynthetic protein degradation. Recovery of photosynthesis took five days following chilling events in the field.

Flowering response and bean quality under different light treatments

Flowering was significantly reduced by 70% treatment during the first 25 months of growth. However, fruit yields were still the largest at 70% treatment compared to the three lower light treatments. This was thought to be an affect of larger canopy photosynthetic rates at 70% transmitted light. However, cocoa grown at 70% treatment produced smaller beans compared to the lower light treatments. Fat extracted from cocoa beans in the NT produced a softer butter than beans originating in Mossman, Queensland.

Leaf gas exchange and growth between north Australian locations

Experimental sites in north Queensland offered the most suitable growing conditions for cocoa. This was primarily attributed to low LAVPD throughout the year promoting large annual photosynthetic rates compared to cocoa grown in the Northern Territory and Western Australia.

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List of Symbols and Abbreviations

^{0}C	Degrees Centigrade
A_{area}	Leaf carbon assimilation per unit leaf area (μmol m^{-2} s^{-1})
AgWa	Agriculture Western Australia
A_{mass}	Leaf carbon assimilation per unit leaf mass (nmol kg^{-1} s^{-1})
A_{max}	Maximum light saturated assimilation per unit leaf area (μmol m^{-2} s^{-1})
ANOVA	Analysis of variance
ATP	Adenosine triphosphate
BR	Brassinosteriods
C3	Three carbon fixation
Car	Carotenoids (mmol m^{-2}; μg g^{-1})
Chl a	Chlorophyll *a* (mmol m^{-2}; μg g^{-1})
Chl b	Chlorophyll *b* (mmol m^{-2}; μg g^{-1})
C_i	Inter-cellular carbon concentration (μmol mol^{-1})
C_i/C_a	Inter-cellular carbon concentration / ambient carbon concentration
CO_2	Carbon dioxide (μmol mol^{-1})
CPHRS	Coastal Plains Horticultural Research Station
D1	D1 Protein
DAG	Days After Germination
DPIFM	Department of Primary Industries Fisheries and Mines
DW	Dry weight (g)
F_m	Maximum fluorescence
F_m'	Light adapted maximum fluorescence
F_o	Minimum fluorescence
F_v/F_m	Efficiency of photosystem II
ΔF / F_m'	Effective quantum yield of photosystem II
g_s	Stomatal conductance (mol m^{-2} s^{-1})
h	Hour
IRGA	Infra red gas analyser
kPa	Kilopascal
LA	Leaf area (m^2)
LAI	Leaf area index
LAR	Leaf area ratio
LAVPD	Leaf to air vapour pressure deficit (kPa)
LED	Light emitting diode
LHC I	Light harvesting complex one

LHC II	Light harvesting complex two
LSD	Least significant difference
N:P:K	Nitrogen : potassium : phosphorus
NACDA	Northern Australian Cocoa Development Alliance
NADP	Nicotinamide adenine dinucleotide phosphate
NPQ	Non-photochemical quenching
NSW	New South Wales
NT	Northern Territory
O_2	Oxygen
PAM	Pulse amplitude modulator
PAR	Photosynthetic active radiation (μmol m^{-2} s^{-1})
PFD	Photon flux density (μmol m^{-2} s^{-1})
PQ	Photochemical quenching
PS I	Photosystem One
PS II	Photosystem two
QDPI	Queensland Department of Primary Industries
RC	Reaction centre
ETR	Electron transport rate
RGR	Relative growth rate (d^{-1})
RH	Relative humidity (%)
RLC	Rapid light curve
RuBP	Ribulose-1,5-bisphosphate
SD	Stomatal density (mm^2)
SLA	Specific leaf area (m^2 kg^{-1})
TCSA	Trunk cross sectional area (cm^2)
TDW	Total dry weight (g)
TGI	Trunk growth increments (cm^2)
TLeaf	Leaf temperature (^oC)
Tr	Leaf transpiration (mmol m^{-2} s^{-1})
UTS	University Technology of Sydney
VPD	Vapour pressure deficit
WA	Western Australia
YE	Yield efficiency (kg cm^{-2})
Ψ	Leaf water potential (MPa)