Impact of popular shade tree species on microclimate and cocoa productivity in agroforestry systems in Ghana

Theresa Kohl[1], Wiebke Niether[1], Issaka Abdulai[2]

[1] Professorship of Organic Farming with Focus on Sustainable Soil Use, University of Giessen,, Germany

[2] Tropical Plant Production and Agricultural Systems Modelling (TROPAGS), Department of Crop Sciences, University of Göttingen, Germany

Introduction

- Ghana accounts for 20% of global cocoa bean production [1]
- Cocoa (*Theobroma cacao L.*) is often cultivated in agroforestry systems

Benefits of cocoa agroforestry	Drawbacks of cocoa agroforestry
Buffering extreme weather conditions [2,3]	Competition for water, nutrients, rooting space [3]
Carbon sequestration [2,3]	Slower vegetative development [6]
Optimal cocoa growth at low shade levels [4]	Decreased resilience under drought [7]
Longer productive lifetime under shade [5]	

- Agroforestry could contribute to climate change adaptation and mitigation, but there is controversial evidence on its impact on yields

Aim: Characterize above-ground morphology of common shade tree species in cocoa agroforestry systems and investigate their impact on microclimate under the canopy and on development and productivity of surrounding cocoa trees.

Methods

- Study site: Boaso, Brong-Ahafo region, Ghana (Fig. 1)
- Data collection: April - June 2022
- Eight common shade tree species (5 reps)
- Eight cocoa trees around each shade tree in three distance zones (Fig. 2)

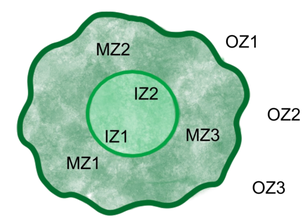

Fig. 1: Location of the study site in Ghana.

Fig. 2: Sampling design for cocoa trees around the shade tree.
IZ = inner zone (within a 3-meter-distance to the stem), MZ = mid zone (under the canopy), OZ = outer zone (outside the canopy). Number = biological repetition.

- Measurements:
  1. Shade tree above-ground morphology
  2. Microclimate under the shade tree canopy
  3. Cocoa tree development and productivity

Results

Shade tree above-ground morphology

Tab. 1: Above-ground morphology of the investigated shade tree species. Mean values and standard error. Last column shows results from a One-Way ANOVA of the impact of species on the parameter (∗ = p < 0.05; ns = not significant).

	Terminalia superba	*Morinda lucida*	*Terminalia ivorensis*	*Milicia excelsa*	*Mangifera indica*	*Ficus capensis*	*Ricinodendron heudelotii*	Alstonia boonei	
Tree height [m]	15.44 ± 2.90	16.18 ± 6.02	17.20 ± 5.02	19.20 ± 5.93	15.42 ± 4.72	20.58 ± 6.77	18.44 ± 5.22	18.32 ± 5.76	ns
DBH [cm]	50.06 ± 21.62	49.84 ± 19.87	46.32 ± 14.51	99.38 ± 28.23	79.05 ± 16.46	126.83 ± 62.95	97.49 ± 27.56	95.81 ± 29.32	*
Canopy diameter [m]	12.09 ± 4.14	11.32 ± 1.88	14.33 ± 6.34	15.74 ± 3.63	15.82 ± 2.19	13.89 ± 8.64	13.42 ± 9.17	9.68 ± 3.65	ns
Crown shape	round	irregular	round – oval	round	weeping	umbrella	irregular	oval – irregular	
Phenology	brevideciduous	evergreen	brevideciduous	brevideciduous	evergreen	brevideciduous	complete deciduous	brevideciduous	

Microclimate under the shade tree canopy

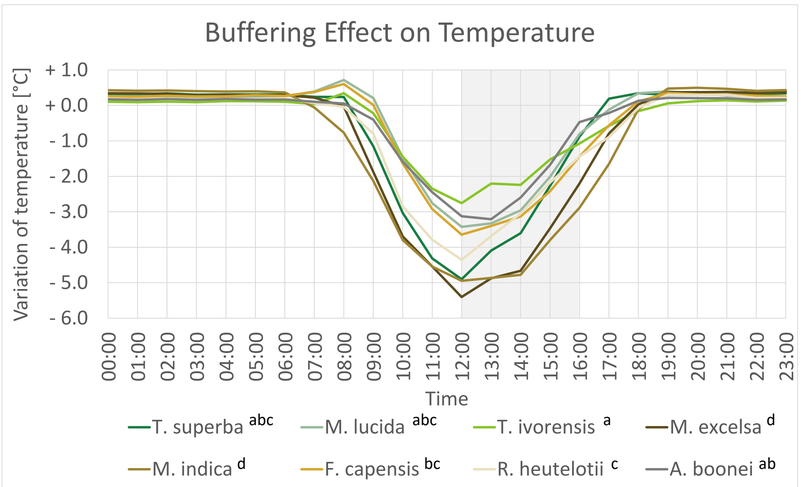

Fig. 3: Buffering effect of shade tree species on temperature throughout the day. Difference to control in full sun. Significance groups a – d describe significant differences (Tukey (HSD): α = 0.05) during the critical period from 12 to 4 pm (shaded in grey).

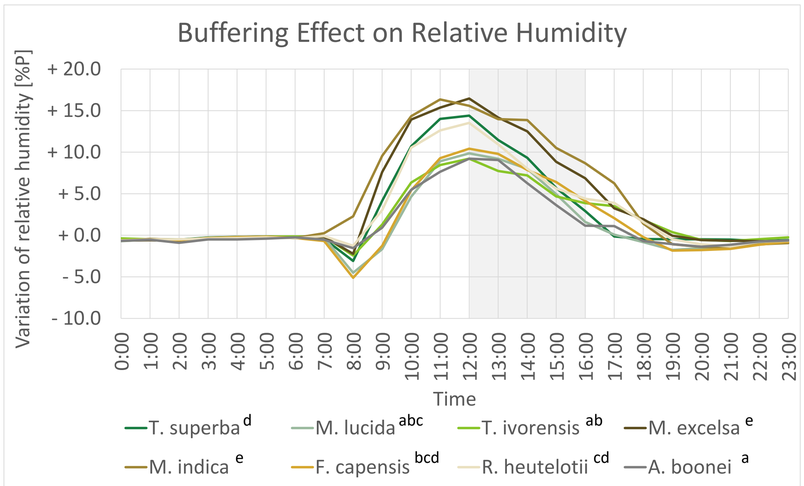

Fig. 4: Buffering effect of shade tree species on relative humidity throughout the day. Difference to control in full sun. Significance groups a – e describe significant differences (Tukey (HSD): α = 0.05) during the critical period from 12 to 4 pm (shaded in grey).

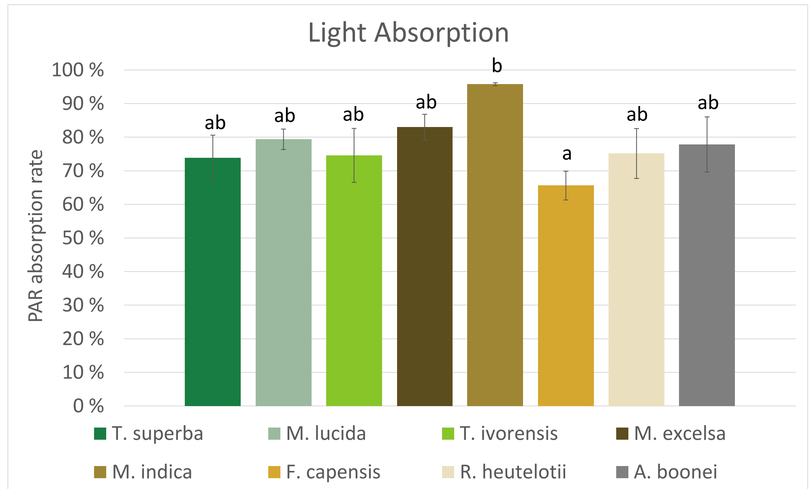

Fig. 5: Absorption of Photosynthetically Active Radiation (PAR) through the shade tree. Measured in morning, noon and afternoon under clear skies. Mean values and standard error. Significance groups a - b describe significant differences (Tukey (HSD): α = 0.05).

Cocoa tree development and productivity

Tab. 2: Effects of shade tree species (A) and distance zones (B) on cocoa development and productivity.
Icons symbolize significance groups (Tukey (HSD): α = 0.05) from low to high mean values. Last column shows results from a Two-Way ANOVA of the impact of species (A) or zone (B) on the parameter (∗ = p < 0.05; ∗∗ = p < 0.01; ∗∗∗ = p < 0.001; ns = not significant).

(A)

	Terminalia superba	*Morinda lucida*	*Terminalia ivorensis*	*Milicia excelsa*	*Mangifera indica*	*Ficus capensis*	*Ricinodendron heudelotii*	Alstonia boonei	
Cocoa Development									
Tree height	-			-	-		-	-	*
DBH									ns
Canopy health	-	-	-	-	-	-			***
Cocoa Productivity									
Flowering intensity									*
Cherelles									***
Share of damaged cherelles									*
Mature pods									*
Share of black pods									ns
Ripe pods									ns
Share of big ripe pods									ns

(B)

	Inner Zone	Mid Zone	Outer Zone	
Cocoa Development				
Tree height				***
DBH				***
Canopy health				***
Cocoa Productivity				
Flowering intensity				***
Cherelles			-	*
Share of damaged cherelles				ns
Mature pods				***
Share of black pods				*
Ripe pods				***
Share of big ripe pods				ns

Conclusions

- No major differences in above-ground morphology between the shade tree species.
- M. excelsa and M. indica have the densest canopies and therefore the highest PAR absorption rates and microclimate buffering effects.
- Cocoa tree development and productivity are more affected by the distance to the shade tree than by the shade tree species.
- Increasing cocoa growth and productivity from inner zone to outer zone could indicate unfavourable growing conditions directly under the shade tree

References

[1] GHANA COCOA BOARD, 2018: Manual for cocoa extension in Ghana. CCAFS manual.

[2] NIETHER, W., J. JACOBI, W. J. BLASER, C. ANDRES & L. ARMENGOT, 2020: Cocoa agroforestry systems versus monocultures: a multi-dimensional meta-analysis. Environ. Res. Lett. 15 (10), 104085.

[3] BLASER-HART, W. J., S. P. HART, J. OPPONG, D. KYEREH, E. YEBOAH & J. SIX, 2021: The effectiveness of cocoa agroforests depends on shade-tree canopy height. Agriculture, Ecosystems & Environment 322, 107676..

[4] GALYUON, I., C. MCDAVID, F. LOPEZ & J. SPENCE, 1996: The effect of irradiance level on cocoa (Theobroma cacao L.): I. Growth and leaf adaptations. Tropical agriculture (73), 23-28.

[5] OBIRI, B. D., G. A. BRIGHT, M. A. MCDONALD, L. C. N. ANGLAAERE & J. COBBINA, 2007: Financial analysis of shaded cocoa in Ghana. Agroforest Syst (71), 139-149.

[6] SCHNEIDER, M., C. ANDRES, G. TRUJILLO, F. ALCON, P. AMURRIO, E. PEREZ, F. WEIBEL & J. MILZ, 2017: Cocoa and total system yields of organic and conventional agroforestry vs. monoculture systems in a long-term field trial in Bolivia. Ex. Agric. 53 (3), 351-374.[8] Zhu, Xiai et al. (2020): Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. In: Plant Soil 453 (1-2), S. 45–86.

[7] ABDULAI, I., P. VAAST, M. P. HOFFMANN, R. ASARE, L. JASSOGNE, P. VAN ASTEN, R. P. RÖTTER & S. GRAEFE, 2018b: Cocoa agroforestry is less resilient to sub-optimal and extreme climate than cocoa in full sun. Global change biology 24 (1), 273-286.

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737