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Productivity, water use and climate resilience of alternative cocoa cultivation systems

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Summary

Global demand for cocoa beans is projected to keep rising while future production is likely to be limited by climate variability and change. Over 70% of the global cocoa supply comes from West Africa, a region expected to be greatly affected by climate change and extreme droughts. Cocoa production in West Africa needs to be adapted to more marginal and extreme climatic conditions, mainly drought, to sustain production and avoid further deforestation of the remaining rainforest for its cultivation. In addition to the climate change effect, current yields are low due to management inefficiencies and soil limitations. Empirical data from cocoa agroforestry system studies are limited compared to those of other perennial crops such as coffee. In addition, the promotion of cocoa agroforestry as a sustainable production system is often based on anecdotes and should therefore be investigated further. There is still a huge knowledge gap on which shade tree species improve and sustain productivity, ecosystem functions (such as increase in flora and fauna diversity), and which are suitable for marginal climates with limited water supply. Studies on the effects of climatic variations on cocoa plant productivity across different regions are lacking although there is a general consensus on the requirement of developing climate change adaption options based on a sound scientific basis for the various regions.

As a contribution towards bridging this research gap and help address current and future cocoa production challenges, for this thesis several studies were performed in Ghana, the second largest and best quality cocoa producing nation: Productivity of different cocoa cultivation systems was studied at three regions along a climatic gradient (from 2014 to 2016). Climate resilience of different cocoa cultivation systems was further investigated in the marginal regions through water use experiments over periods of wet, dry and extremely dry.

Overall hypotheses of the thesis were that (i) climatic region does influence cocoa productivity, and (ii) agroforestry increases resilience of cocoa plants to marginal and extreme climatic conditions.

In **chapters 2 and 3** of the thesis, characterizations of yield gaps, soil fertility status and cocoa cultivation systems were conducted through interviews and on-farm inventories of 150 cocoa farmers and their farms along a climate gradient within the cocoa belt of Ghana. The regions which are between 100 to 150km apart were denoted as dry, mid and wet, based on estimated average annual rainfall of 1200, 1400 and 1800mm from north to south of the cocoa belt respectively. These regions are representative of current and future cocoa climatic regions of West Africa. Based on yield gap and soil fertility evaluations, it was found that the study regions were significantly different. Yield levels in the wet region were significantly higher than in the dry region, mainly due to suitable climate and management intensification. Lower yield in the dry region was due to climatic limitation and farmer's adaptation strategies in terms of income diversification and using less external inputs. Cocoa only contributed 50% to farmer's income in the dry region while non-cocoa crops and off-farm income activities contributed 30 and 20%, respectively. For farmers in the mid and wet regions, cocoa income contributed more than 80% to their annual income, indicating higher intensification and specialization. Soil fertility also varied significantly between the regions but overall the fertility status was low. From these findings it was established that different climatic zones will require different cocoa farm management and soil fertility improvement strategies. Closing yield gaps in the dry region requires improvement in pesticide and fungicide use in addition to fertilizer application. In the mid and wet regions, the control of parasitic mistletoe, improved fertilizer use and the use of quality planting materials are recommended for yield gap closure. Shade tree use and management in cocoa agroforestry systems practiced by farmers were further characterized across all climatic regions. This was to evaluate the existing and potential use of shade trees as a measure to adapt cocoa production systems to climate change. The current cocoa agroforestry systems were characterized for the two main systems of "medium" and "low shade". Medium and low shade systems dominated the dry and wet regions, respectively. Cocoa yield under medium shade system was significantly lower in the wet region but there was no difference in the dry and mid regions. It is therefore recommended that, shade tree selection for cocoa agroforestry should be climatic region-specific to minimize trade-offs between the productivity of cocoa farms and other ecosystem services.

In **chapter 4**, a detailed water use experiment was conducted in the dry region to help understand the effect of different cultivation systems on water use and drought resilience. Cocoa and shade tree water uptake (sap flow) was studied with a thermal dissipation method using Granier sensors. Soil water and microclimatic conditions were also monitored from November 2014 – March 2016. This experiment tested cocoa agroforestry as a potential adaptation strategy in sub-optimal and extreme drought conditions. Cocoa in full sun was compared with agroforestry systems: shaded by (i) a leguminous tree species, *Albizia ferruginea* and (ii) *Antiaris toxicaria*, the most common shade tree species in the dry region. The climate and drought events during the study period served us as a proxy for projected future climatic conditions in marginal cocoa cultivation areas of West Africa. The 2015/16 El Niño event resulted in the strongest drought in the region since 1982/83 when a similarly strong event occurred. Soil water was reduced under the shaded systems during drought events. Cocoa plants under *Albiza* and *Antiaris* recorded 100 and 77% mortality, respectively, during the extreme drought period. Cocoa plants under full sun survived and recovered after the drought while those under shade did not. It was then established that during extreme drought, the role of shade trees on cocoa plants became critical as competition for soil water intensified. Water limitation was found to override microclimatic benefits by the studied shade tree species. Cocoa plants under full sun showed a higher level of resilience and acclimatisation capacity to drought than shaded cocoa. These results call for further detail studies, looking above- and below-ground, to critically evaluate the promotion of shade tree use as a climate change adaptation strategy for cocoa cultivation planning especially in West Africa.

Differences in cocoa plant productivity between shaded and full sun systems across the climatic regions were studied in **Chapter 5**. Three treatments of high shade, medium shade and open sun plots were assessed across the three climatic regions. Three cocoa plots of each system with 20 uniformly distributed cocoa plants were monitored monthly for a whole year. The results showed higher cocoa plant yield (harvested pods) under full sun conditions than in the shaded systems in the low rainfall dry region. In the mid and wet regions, no significant differences were observed between the systems. Both cocoa plant productivity and drought resilience are therefore negatively affected by shade trees under a marginal cocoa climate. The use of shade trees as climate change adaptation strategy especially in the mid region where by 2050 marginal climatic conditions are projected, need to be carefully reconsidered. For the dry region, a potential climate change adaptation strategy would be changing from cocoa to crops that are more productive and are faced with lower climatic risk. One example of such a crop may be cashew, which is more resilient to drought than cocoa and also has a high economic value. The development of more drought tolerant cocoa planting materials could also be an option to sustain cocoa production under the projected climate change. In the mid region, where the projected climatic conditions will be similar to those of the current dry region, shade trees with proven complementary soil water use under natural conditions could be integrated with cocoa. Alternatively, a full sun system is recommended through land sparing approach to ensure biodiversity conservation in the cocoa landscape. For the wet region, where water limitations are not expected, well managed cocoa agroforestry systems could be practiced to ensure sustainable yield and biodiversity conservation. Overall, this study provided detailed results on climatic zone-specific cocoa management as well as options to help adapt plant production systems to climate change and extreme drought within the “cocoa landscape”.

To my dear wife and best friend, Wallam

My children, Hajar and Rayyan

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