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Christian Andres "Transdisciplinary systems research to reduce the cocoa swollen shoot virus disease in Ghana", ETH Zurich, 2017

1. Problem statement

Ghana is the second largest producer country of cocoa (*Theobroma cacao* L.) in the world. The common saying "Ghana is cocoa, cocoa is Ghana" underlines the economic and social importance of cocoa in Ghana, where the livelihoods and food security of around 800'000 families (3.2 million people, or 18% of the country's population above 15 years) depend on revenues from the crop. One of the major factors limiting cocoa productivity for those farmers is the cocoa swollen shoot virus disease (CSSVD). Since the only effective treatment for CSSVD is to cut infected trees and replant with disease free planting material, the livelihoods of those people are threatened directly by the disease. Because cocoa only starts yielding 4 -6 years after planting, a so-called "hunger gap" is common in cocoa farmer families, meaning that the families lack financial resources during this time to buy staple crops in order to ensure their food security. The Ghanaian government has tried to contain the disease through an official eradication campaign that started back in 1946. Since then, more than 300 million trees have been cut out and replaced, which had severe economic consequences for all the actors involved in the cocoa value chain, from farmers to the government.

Hence, the development of preventive control measures and strategies to both prevent the spread and mitigate the severity of the disease are of utmost importance. 80 years of research on preventive control measures have mainly focused on resistance breeding, mild strain cross-protection (inoculation of cocoa seedlings with a mild strain of the virus to protect against the severe strain) and control of mealybug vectors. In addition, research has recommended cordon sanitaire and removing alternative host trees as further prevention measures. In spite of promising results from those research activities, however, CSSVD is more prevalent in the field than ever before. Meanwhile, diversification measures such as agroforestry and barrier (strip) cropping have received less attention in past research. Those measures hold a high potential to mitigate the severity of CSSVD symptoms through shading (agroforestry) and to reduce the spread of the disease by providing physical barriers (barrier cropping).

2. Research questions

I carefully checked the adequateness of the research questions, which I had formulated in the initial proposal, as well as the feasibility of their implementation during an extensive induction phase that lasted from spring to autumn 2015. In this period, I exchanged with various stakeholders from policymakers through researchers and extension officers to farmers in order to make sure that the research priorities I set were relevant and targeted at bringing about change for the benefit of all. This transdisciplinary process was an excellent opportunity to develop a deeper understanding of the situation the various stakeholders on the ground were facing, and to appreciate the wickedness of the issues around CSSVD.

A lot of information on CSSVD is available from published and unpublished sources (grey literature). but no quantitative assessment of this vast body of data had been done so far. Therefore, the guiding research question for the first part of the study was:

1. “What is the effectiveness of the main CSSVD control options?”

The influence of diversification on plot scale (shading by agroforestry trees) on CSSVD had not been studied so far. Therefore, the guiding research question for the second part of the study was:

2. “What are the effects of diversification (at plot scale) on CSSVD symptom severity?”

Finally, the guiding research question to investigate the issue of farmers' adoption of research-based recommendations for CSSVD control was:

3. “How can we enhance the adoption of CSSVD control options in Ghana?”

By covering those aspects, I aimed at a holistic understanding of the issues in cocoa production in order to come up with feasible solutions.

3. Objectives

When trying to tackle a problem as complex as CSSVD, it is important to have a very good idea about the point of departure, i.e., asking yourself the question: what do we already know? Therefore, I first embarked on consolidating the large body of knowledge about preventive control measures for CSSVD, as this information was fragmented and had never been systematically evaluated and quantitatively assessed before. Not only did this activity give me a comprehensive overview about the knowledge in the field, it also provided a basis for further research I carried out during my PhD. I found that there is a significant knowledge gap about the potential of agroforestry systems to reduce the severity of CSSVD, and that the adoption of promising CSSVD prevention measures by farmers remains limited.

Since I found that only one study carried out under controlled research conditions had indicated the potential of agroforestry to reduce the severity of CSSVD symptoms, I decided to investigate this potential further and see whether potentially reduced CSSVD symptom severity would also translate into higher cocoa yield under actual farmers' field conditions. Furthermore, I wanted to determine the optimal range of shading to reduce CSSVD symptom severity, which led to the questions about the definition of the term "shade", and about the real processes behind observed differences in shaded compared to non-shaded systems. “Shade” as such could be effective, but also really “just” a proxy for agro-biodiversity, soil fertility, soil moisture and many other factors. However, studying the underlying causal factors of shade, I found limits to the feasibility of such research. Nevertheless, I was able to determine which of the factors agro-biodiversity, soil fertility and high-light stress may have had the strongest influence.

However, even if researchers develop effective preventive control measures for CSSVD, these can only have a real impact if farmers adopt them. I also investigated this factor because

I found that the adoption of promising CSSVD prevention measures by farmers remains limited, and that the main reasons for this are largely unknown.

4. Methodological approach

The large body of knowledge on preventive control measures for CSSVD is fragmented and many publications are not easily accessible. Furthermore, the literature has never been systematically evaluated and quantitatively assessed. Hence, we consolidated this knowledge with an extensive literature review followed by meta-analysis to identify the pertinent research gaps. Out of 423 publications on CSSVD-related issues, I selected 34 studies, which contained 52 datasets on seven different preventive control measures.

Furthermore, I studied the effects of shade on CSSVD symptom severity, capsid damage and cocoa yield along a gradient of increasing shade tree abundance in smallholder cocoa farms in Ghana. I also measured photosynthetic active radiation and assessed soil fertility in order to elaborate on potential causal factors for possible shade effects on CSSVD symptom severity.

Finally, I evaluated the current adoption of the prevention measures cordon sanitaire, barrier (strip) cropping, using partly tolerant hybrid seedlings and removing alternative host trees, and identified their adoption constraints for farmers. I conducted a quantitative survey with 396 farmers in the Eastern and Western Regions of Ghana, held six focus group discussions with eight to eleven participants each, and hosted a multi-stakeholder validation workshop with 31 key actors from the cocoa value chain of Ghana. The research was delineated into the following activities and sub-activities:

Activity 1: literature review and meta-analysis

Activity 1.1: Literature review about the main CSSVD control options

There is a lot of anecdotal knowledge about the main CSSVD control options, especially in the library of African institutions such as CRIG. However, this information was fragmented and had never been systematically evaluated to provide evidence. Therefore, I conducted an extensive review of the relevant literature from both peer-reviewed and non-peer-reviewed sources as well as grey literature.

Activity 1.2: Preparing the data matrix for meta-analysis

A set of improved practices (e.g. use of resistant varieties, barrier (strip) cropping, etc.) and the effect size (i.e., reduction of infection due to a particular improved practice) was defined. After that, the eligible studies were evaluated, followed by parameterization and integration of the information into a common data matrix for meta-analysis.

Activity 1.3: Comprehensive meta-analysis

Finally, a comprehensive meta-analysis was carried out. Meta-analysis is a powerful statistical technique to combine and compare results from a range of independent studies, by weighing the results according to their different precisions, reflected in their standard deviations and underlying replications. Meta-analysis has rapidly gained popularity as it offers an opportunity to review the exponentially growing body of knowledge in a way that reduces bias associated with traditional narrative reviews.

Activity 2: In-depth study of diversification at plot scale

The influence of diversification at plot scale (i.e., shading by agroforestry trees, barrier (strip) cropping, etc.) on CSSVD symptom severity had not been studied so far. Therefore, I conducted an in-depth study on this factor. I estimated shade tree cover, identified shade tree species and assessed CSSVD symptom severity on a categorical scale from 1-10. Subsequently, I established the relationships between CSSVD symptom severity, shade levels and diversification indices (e.g. Shannon Index, etc.), taking into account important biophysical and socio-economic co-factors (e.g. soil fertility parameters, management practices and capsid damage).

Activity 3: Enhancing the adoption of CSSVD control options

This task can be tackled in two ways: bottom-up or top-down, i.e., starting from the farmers (study on socio-economic adoption constraints) or from the government/ industry (study of the political context). An effective integration of the two perspectives is most likely to create impact. Therefore, in a first step I obtained data on socio-economic adoption constraints using semi-structured interviews and focus group discussions with farmers. Such information included farm sizes, land tenure. as well as the farmers' i) knowledge and management of CSSVD and improved practices, ii) educational level, iii) affiliation to a cooperative/farmer group, iv) inclusion in extension programs, v) access to information, vi) perceptions of current production and willingness to cut and replant cocoa plantations, and vii) farmers' age.

Secondly, a study of the political context helped me to understand the complexity in which the CSSVD problem is embedded, and to identify how challenges in the farmers' context can best be addressed. For example, hindering factors for farmers to engage in sustainable cocoa production systems were elaborated in a transdisciplinary stakeholder workshop that was informed by the previously established farmers' perspectives/needs. This led to information that was useful to suggest future steps toward the elaboration of an implementation action plan to enhance the dissemination of feasible CSSVD control options (adaptation of existing extension programs of Cocoa Health and Extension Division (CHED)).

I aimed at fostering adoption by farmers by applying participatory approaches such as on-farm research, farmer field days and exchange meetings that emphasized on education about CSSVD (spread of the disease. feasible control options, sources of information. etc.). Furthermore, products relevant for farmers' education such as illustrated leaflets and videos on best practices of CSSVD management that can be shared by farmers on mobile phones using Bluetooth technology were elaborated and distributed. These activities stimulated mutual learning by integrating different forms of knowledge and making it visible to different stakeholders. A more detailed description of the methodological approach is outlined in thesis chapters 2, 3 and 4.

5. Results and discussion

Results from Activity I (literature review and meta-analysis) showed that resistance breeding and mild strain cross-protection may reduce CSSVD infection by 30 percent, while the potential of diversification measures (shading/agroforestry and barrier (strip) cropping) seems to be considerably higher (40 and 85 percent, respectively). However, there is a lack of evidence because of a low number of studies about diversification measures, indicating that our results have to be interpreted with care and calling for more research in this area.

Results from Activity 2 (in-depth study of diversification at plot scale) showed that both CSSVD symptom severity and cocoa yields followed quadratic curves, and were found to be lowest and highest in plots with 54% and 39% shade, respectively. The simulated optimal shade levels for CSSVD symptom severity and cocoa yield overlapped between 45% -53%, indicating that agroforestry systems with around 50% shade cover may be an optimal coping strategy to balance CSSVD symptom severity versus reduced cocoa yield until diseased cocoa is replaced with more resistant varieties. Furthermore, my results suggest that rather than increased soil fertility, reduced high-light stress may have been responsible for the shade effects on CSSVD symptom severity.

A major advantage of agroforestry systems is that the high crop diversity allows for harvests and income already during the first year of plantation establishment. This allows agroforestry farmers to avoid the “hunger gap” that occurs in cocoa monocultures, which only start to produce after 4-6 years. Other advantages include maintenance of soil fertility through continuous addition of organic material from pruning interventions, as well as natural self-regulation of pests and diseases through increased agro-biodiversity of the systems (habitats for natural pest antagonists).

Results from Activity 3 (enhancing the adoption of CSSVD control options) showed that the adoption of prevention measures remains limited. Farmers with a more extensive social network, a larger farm size, more secure land tenure rights and more knowledge about the prevention measures were more likely to adopt them, especially barrier (strip) cropping. hybrid seedlings and removing alternative host trees. Lack of knowledge about the measures was the single largest barrier for adoption, with 51 % of all the participating farmers not even being aware of the prevention measures. My results suggest that a farmers' social network has the highest potential to be an effective source of information, which was in line with the finding that the information flow between farmers and other stakeholders in Ghana is a critical factor affecting knowledge spread and thus the adoption of CSSVD prevention measures.

6. Conclusion and outlook

The need for multi-dimensional innovation to address the CSSVD issue

The various issues around CSSVD are highly complex, touching different stakeholders and requiring ecological, technical (biological, mechanical and organisational), socio-political and economic innovations to be addressed. These include the reshaping of both the design and the management of cocoa production systems at farm and landscape levels, as well as the development of resistant cocoa varieties, the production of sufficient barrier (strip) crop and shade tree seedlings and biological control options for the mealybug vectors. Decentralised nurseries are also desperately needed to provide farmers with seedlings in a timely manner. The pressure on CHED extension officers to deliver data on CSSVD occurrence in their respective districts is high. Here, a mapping tool for CSSVD occurrence using drone imagery and normalized difference vegetation index (NDVI) could be of great help to reduce the workload on CHED extension officers, so that they can better meet the explicit wish of farmers to be visited more frequently. Appendix C of the thesis outlines a concept for a study on the development of this novel mapping tool that came up during the course of the research, but has not been brought to completion so far.

As for the design of production landscapes, the importance of landscape connectivity should not be underestimated. CSSVD can only spread if there are uniform production landscapes, i.e., vast acreages of connected cocoa farms that facilitate the movement of the mealybug vectors. Some preliminary results suggest that dense cropping correlates with CSSVD prevalence (unpublished data), which makes sense when considering the behaviour of the mealybug vectors, which spread the disease slowly by moving on interlocking branches of adjacent trees. As the treatment of vast acreages of cocoa farms is challenging insofar as it involves the persuasion of many farmers to cut and replant their farms, policy reform is urgently needed in this area. Policies should be formulated which direct farmers to delimit their cocoa plantation with a strip of at least 10 m of a non-host crop (e.g. coffee) when they renew their plantation (barrier (strip) cropping). Another policy should aim at preventing that a new cocoa plantation connects two existing cocoa farms and at maintaining a distance of at least 10m between cocoa areas. However, changing Ghana's cocoa production landscape from uniformity to a complex agro-ecological matrix of cocoa agroforestry systems is a gradual process that will require time. Appendix B of the thesis outlines a concept for a study on the importance of landscape connectivity for reducing the spread of CSSVD that came up during the course of the research, but has not been brought to completion so far.

Cocoa farming in Ghana needs to reinvent itself, leaving behind the reputation of being a poverty trap of parents and grandparents, and becoming a viable business alternative for the youth that combines well with innovative approaches such as ecotourism. The mechanisation of cocoa production is also of vital importance to attract the youth to go into cocoa farming, as is the delivery of information using adequate information channels and media (e.g. videos on mobile phones) that portray cocoa farming as a beautiful work reconnecting humans to nature and leading to ecosystem health. In this respect, novel ICT solutions to improve the communication with farmers are vital.

At the policy level, an incentive scheme for nature-friendly cocoa production is needed to reverse the trend of cocoa farmers going for full-sun systems that provide the quickest return on their investment but have detrimental effects on the environment and potentially also on human health. Such a scheme may include support payments for farmers who wish to get access to credits, in order to foster a sense of entrepreneurship among future cocoa farmers. Finally, the prompt revision of Ghana's land tenure system is vital to counteract the continued fragmentation of Ghana's cocoa landscape into ever-smaller farms due to inheritance and sharecropping practices.