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RESPONSE TO EDITOR

WILEY Global Change Biology

Cocoa agroforestry is less resilient to suboptimal and extreme climate than cocoa in full sun: Reply to Norgrove (2017)

The critique of Norgrove (2017) addresses two main points, which are discussed below:

1. Resilience of cocoa agroforestry vs. full sun under extreme climatic conditions

In our study Abdulai et al. (2018), we covered extreme climatic events, a heat-wave combined with a severe dry season lasting longer than usual and killing cocoa trees under shade. These climatic conditions were not only observed at our study plots but also in the larger cocoa cultivation region (Figure 1). In line with our

FIGURE 1 (a) Map of Ghana with cocoa climatic transect, (b) in additional monitored plots along shade gradient in the region (Abdulai et al., 2017), plots with high shade cover suffered much drought stress and mortality in the studied region (c) cocoa plot during the drought shaded and (d) unshaded plots

observations, "certain cocoa cooperatives in Ivory Coast reported that shade trees in their cocoa fields accentuated the drought stress during the 2015 drought event" (Andrew Brooks,[1] pers comm).

In the specific case of our study, the two shade tree species associated with cocoa resulted in strong competition for water and became a disadvantage to the cocoa plants contrary to expected positive effects. So far, the general discourse in the cocoa sector has been that shade trees are needed for climate change/drought adaptation. However, we show it is rather a function of location, severity of the drought event, shade tree species type and root characteristics as concluded by Norgrove. There are clearly different shades of grey that need to be considered.

We do not advocate promotion of full sun or shade tree cocoa agroforestry as the best adaptation strategy, but rather encourage conducting further studies in this respect, in line with what Norgrove suggests as "cocoa merits a fine sampling." We also acknowledge the further challenge in planning such studies due to unpredictable occurrence of such extreme drought events and the limitations of using experimental droughts. In experimental drought studies in field conditions, important factors such temperature, radiation and vapour pressure deficit increases associated with extreme droughts do not occur (Schwendenmann et al., 2010).

2. Sampling design

Graefe et al. (2017) reported 1,576 cocoa trees/ha and 49 shade trees/ha for the study region. Therefore, the cocoa tree density at the sap flux site can be considered representative. One main constraint of our experimental set-up was certainly technical requirements for conducting sap flux studies, which limited the selection of shade tree species for the study. However, *A. toxicaria* is one of the most common shade tree species in the region, which can be found in nearly all farmers' cocoa plots (Graefe et al., 2017). A similar approach of studying individual shade tree effect on cocoa has been applied for soil fertility evaluation under shade tree cocoa agroforestry in Ghana (Blaser, Oppong, Yeboah, & Six, 2017). On justification of plot size for the full sun plot, we did not restrict the size and, therefore, selected available area under no shade tree influence.

We do acknowledge that there are less cocoa trees under direct shade tree influence considering the shade and cocoa tree density. Recommending planting of cocoa away from shade tree canopy as suggested by Norgrove, however, would defy the benefit of microclimate buffering, observed in our study when drought was not extreme, and reduced cocoa plant density. Actually, it would move the system closer to a full sun cocoa system.

Finally, the conclusions from our paper were put rather cautiously and restricted to the specified situations where extended droughts already occur presently or then are likely to occur more frequently in the future. Only for such situations, we recommended a shift away from cocoa to other crops and income sources for improving farmers' livelihoods. This is of paramount importance for adaptation planning since climate change scenarios predict drier climate for the northern cocoa belt of West Africa (Schroth, Läderach, Martinez-Valle, Bunn, & Jassogne, 2016).

[1]Andrew Brooks is Olam's Head of Cocoa Sustainability and in that position has been advocating for the use of shade trees in Ivory Coast.

Keywords
agroforestry, Cocoa, extreme heat and drought, Ghana, soil water

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