The Effect of Tree Shade on Biophysical Constraints to Robusta Coffee in Areas with Varying Rainfall in Uganda

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Abstract

In Uganda, Coffee (*Coffea spp*) is affected by several biophysical constraints, which are associated with less than 30% productivity. These include climate variability, especially rainfall, increased temperatures, and drought that have adverse effects on abiotic and biotic factors, resulting in low coffee yield and increased yield gaps. An intervention to mitigate the impact of rainfall variability, low soil moisture, and reduce associated pests, diseases, and soil fertility decline is the tree shade. Although tree shade may have ecological, abiotic, biotic, and productivity benefits, there are limited studies on its impact on biophysical factors in Robusta coffee (*Coffea canephora*) production across rainfall gradients in central Uganda. Therefore, this study investigated the rationale and harnessing of tree shading Robusta coffee for enhanced productivity through alleviation of moisture stress, nutrient deficiencies, pest incidence, and yield under reducing rainfall in smallholder cropping systems.

Using field data collected through cross-sectional household surveys, diagnostic studies and a longitudinal nested study, data on farmers' management practices, major perceived constraints and rainfall received at the farm were collected and analysed. Besides, measurements across rainfall gradients (low (<1100 mm year^{-1}), moderate (1100 – 1200 mm year^{-1}) and high (>1200 mm year^{-1}) were carried out to test the influence of tree shade on microclimate (temperature and humidity), topsoil water content, soil fertility parameters, pests, coffee yield components, yield as well as tree shade rainfall interactions in central Uganda. Data were analysed using parametric and nonparametric methods in STATA and R statistical packages.

The results indicate that actual annual rainfall was significantly ($P<0.05$) higher in high and lower in low rainfall thresholds. The management practices and perceived constraints varied among the rainfall thresholds with fewer farmers using climate-resilient and yield-enhancing practices. The most perceived constraints included drought and unpredictable rainfall, diseases, and pests. The main pests and diseases during household and diagnostic surveys were black coffee twig borers (BCTB) (*Xylosandrus compactus*) and coffee berry borers (CBB) (*Hypothenemus hampei*). The main diseases were coffee wilt (*Fusarium xylarioides*), coffee leaf rust (*Hemileia vastatrix*), and coffee blister (*Colletotricum coffeanum*). The proportion of pests, diseases, microclimate and soil fertility parameters varied significantly ($p<0.05$) between rainfall thresholds, being higher in high and lower in low rainfall thresholds. The Robusta coffee yield and the yield gaps also varied significantly ($p<0.05$) between rainfall thresholds, with a lower average yield and a higher yield gap in the high rainfall than other thresholds. The attainable coffee yield was 1,492 kg ha^{-1}, and the overall mean yield was 835 kg ha^{-1}. The most limiting factors in coffee fields were soil fertility parameters, tree density, and coffee-banana ratio which varied significantly ($p<0.05$) with rainfall thresholds. There was a significantly ($p<0.001$) higher shade tree density per hectare at low than at other thresholds. Similarly, the coffee-to-banana ratio was significantly ($p<0.05$) higher at the moderate than high and low rainfall thresholds. Besides, tree shade significantly ($p<0.05$) enhanced soil fertility, soil moisture content, buffered temperature, and humidity across rainfall thresholds. Furthermore, there was reduced pest and disease infestation, especially in the low rainfall thresholds and unshaded plots. In addition, tree shade affected coffee production and yield components, which varied between rainfall thresholds but not shade levels.

The results imply that tree shade is key in Robusta coffee management amidst rainfall variability. However, it may have increased coffee pest incidences due to higher humidity, while it affected yield through reduced flowering, photosynthesis, and competition for available light, water and nutrients. Hence, optimal shade management (less than 60%) is required at the threshold level to reduce humidity, which favours pest and disease infestation and increases adaptation to climate variability for smallholder Robusta coffee farmers. The results can inform tree shade policy in Robusta coffee smallholder farms for adaptation and mitigation strategies due to its positive impact on increasing temperatures, and declining soil fertility and moisture, thereby contributing to achieving the projected target of 20 million 60 kg bags year^{-1} and US$1.5 billion from coffee.