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Crop vs. tree: Can agronomic management reduce trade-offs in tree-crop interactions?

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ABSTRACT

Scattered trees dominate smallholder agricultural landscapes in Ethiopia, as in large parts of sub-Saharan Africa (SSA). While the inclusion of scattered trees could provide a viable pathway for sustainable intensification of these farming systems, they also lead to trade-offs. We carried out a study to: 1) explore the rationale of farmers to maintain on-farm trees beyond crop yield; 2) quantify the impact of agronomic practices on the outcome of tree-crop interactions; and 3) analyse partial economic trade-offs for selected on-farm tree species at farm scale. We recorded agronomic practices within the fields of 135 randomly selected farms from seedbed preparation to harvesting. A multivariate analysis showed that farmers maintained on-farm trees because of their direct timber, fencing, fuelwood, and charcoal production values. Trees generally had a significant negative effect on maize yield. Mean grain yields of 1683, 1994 and 1752 kg ha^{-1} under the canopies of *Cordia, Croton* and *Acacia,* respectively, were significantly lower than in their paired open field with mean yields of 4063, 3415 and 2418 kg ha^{-1}. Besides, more income from trees was accompanied by less income from maize, highlighting trade-offs. However, agronomic practices such as early planting, variety used, improved weed management, fine seedbed preparation and higher rates of nitrogen fertilizer significantly reduced yield penalties associated with trees. We found an inverse relationship between land size and on-farm tree density, implying that the importance of trees increases for land-constrained farms. Given the expected decline in per capita land size, scattered trees will likely remain an integral part of these systems. Thus, utilizing 'good agronomic practices' will be vital to minimize tree-crop trade-offs in the future.

1. Introduction

Scattered trees within crop fields are an integral part of smallholder agricultural landscapes in Ethiopia and large parts of sub-Saharan Africa (SSA) (Lengkeek et al., 2005; Endale et al., 2017). Fast population growth in the region is expected to cause greater demand for food, fuel and fibre, intensifying the pressure of agricultural production on the environment (Yu et al., 2012). The century-old practice of managing scattered trees on crop fields has been suggested as one of the pathways for sustainable intensification of smallholder agriculture in the region (Pretty et al., 2011). In addition to their direct provision of food, fibre and fuel (Alavalapati et al., 2004; Calvet-Mir et al., 2012), scattered on-farm trees are known to provide multiple ecosystem services (Asaah et al., 2011; Ango et al., 2014). Planted fast growing tree species or naturally grown scattered mature trees in crop fields, have been advocated as an affordable and sustainable means to improve and sustain soil fertility for smallholders in SSA (Glover et al., 2012). They can be used to minimize the problem of soil fertility decline (Akinnifesi et al., 2011), which is reported to have an indirect negative impact on household food security in Ethiopia (Haileslassie et al., 2005). Even under situations where short-term negative effects of on-farm trees on crop yield may prevail (Clough et al., 2011), they were reported to have long-term positive effects on the overall system productivity and sustainability (Malézieux, 2012).

By contrast, on-farm trees may compete with annual crops for resources. Their interactions with crops involve complex management decisions in order to maximize total farm-level benefits. Regardless of established ecological and provisioning contribution of trees (Bayala et al., 2002), their direct contribution to increased crop yield is often contested (Coulibaly et al., 2014) and context specific (Brandt et al.,

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2012). Moreover, tree shade reduces light penetration to understory crops, limiting their rate of photosynthesis (Ong and Kho, 2015). While crop yield penalties are expected as a result of tree-crop competition for resources, farmers still maintain trees on their farms. This conforms with the findings of Boffa (2000) who suggested parkland trees are planted and maintained for their benefits in the overall farming system, not solely for their direct effects on crop yields. Den Biggelaar and Gold (1996) also showed that preferences for indigenous on-farm tree species are driven by context-specific values and their multiple uses rather than solely by financial and economic factors. On-farm trees are also maintained for their social and cultural values (Gustad et al., 2004). On the other hand, Kindt et al. (2004) found that woody species richness tended to increase with land size in smallholder systems, while Lengkeek et al. (2005) found that the number of on-farm trees declined with increasing land size. This is, perhaps, because managing trees with crops requires extra labour, forcing farmers with larger farms to manage relatively fewer trees. A recent study from the Oromia state of Ethiopia revealed that adoption of exotic tree species and maintenance of indigenous ones depended on farm assets such as total land size and income from livestock (Iiyama et al., 2017). Total land size affected positively the maintenance of indigenous tree species, while increased income from other farm enterprises had a negative influence on it.

Farmers potentially minimize tree-crop competition effects by managing both crops and trees. While many studies assessing the negative effects of tree-crop interaction have focused on management practices that manipulate the tree component such as root and canopy pruning (Bertomeu et al., 2011), studies exploring the potential impact of manipulating the crop component are scarce. Changes in crop planting schedules, and adaptations of crop genetic characteristics such as maturity class, competition tolerance, vulnerability to pests, and sensitivity to tree shade can be used to improve crop competitiveness with trees (Rosenzweig et al., 2004). Although the impact of these agronomic managements have been widely studied in the absence of trees (Kolb et al., 2012), it was seldom the case in tree-crop systems. On the other hand, differences in biophysical conditions resulted in different competition mechanisms, forcing farmers to practice different management options to minimize trade-offs in tree-crop production systems elsewhere (Huth et al., 2010). We expect that farmers may adapt agronomic practices such as field preparation, planting date, fertilization rate, variety selection, weeding, and cultivation in order to minimize trade-offs in tree-crop interactions. Thus, the overarching objective of the study was to understand farmers' motivations, impacts on crops and economic trade-offs from scattered trees in a semi-arid and two sub-humid agricultural landscapes in Oromia, Ethiopia. Specifically, we aimed: 1) to explore farmers' rationale of maintaining trees on-farm, beyond the effects on crop yield; 2) to quantify the impact of agronomic practices on the outcome of tree-crop interactions; and 3) to analyse partial economic trade-offs for selected on-farm trees at farm scale.

2. Materials and methods

2.1. Study area

We used a combination of household survey and field measurements in two contrasting agroecosystems (semi-arid and sub-humid) in Ethiopia (Table 1). We selected two sites from a sub-humid agroecoregion and one from a semi-arid agroecoregion. The semi-arid site – Meki – is located in the Central Rift Valley of Ethiopia, while the two sub-humid sites – in Bako – are located in the western part of the country. All study sites are similarly characterised by mixed crop-livestock farming systems, with substantial on-farm tree cover as a dominant feature. Trees are scattered within crop fields, retained during selective clearing of the original vegetation (Tolera et al., 2008).

2.2. Sampling and data collection

2.2.1. Sampling and yield estimation

We purposively selected three indigenous on-farm tree species, which were the most dominant in each of the sites. *Cordia africana* (Cordia) and *Croton macrostachyus* (Croton) were the most dominant species in Bako, whereas *Acacia tortilis* (Acacia) was the most dominant in Meki. To simplify reporting, we used genus names (given in the parenthesis) when referring to these species in the rest of the paper. For each species, we randomly selected 45 farmers who managed trees on maize fields, creating a combined sample of 135 farms. We purposefully selected one field from every farm for data collection using the criteria: (1) the tree species of interest was grown within maize fields, (2) the selected tree was located in maize field isolated from other on-farm trees by at least 40 m, and (3) open field and under canopy plots had similar landform and cropping history. In addition, individual trees for a particular species were selected to be as similar as possible. We measured tree heights and canopy diameters (East-West and North-South) for the sampled trees. We fixed the DBH, canopy radius and height of the selected trees to be within 10% of the size of the first randomly selected tree, in order to maintain reasonable similarity between selected trees.

We established three sampling plots, each 4 m^2 in size, for each of the 135 farms (Fig. 1). One plot was established for maize in the open field, which was at least 40 m away from the nearest tree, and two plots, from which a single average yield was computed to account for under canopy heterogeneity, were established at a distance of 2 m from the tree trunk (referred to as under tree canopy maize). We collected maize yield and yield components from all plots. Maize samples were oven-dried for 48 h at 60 °C to determine total dry biomass and grain yields.

2.2.2. Soil moisture and solar radiation

For all plots described in the previous section, we measured topsoil moisture content three times between silking and physiological maturity using ML3 ThetaProbe© moisture sensors (Delta-T-Devices, 2013). For each measurement time, we sampled soil moisture from five points, randomly selected within the plots (Fig. 1a), and used the mean value from these five points for analysis. Similarly, for each measurement time, we measured photosynthetically active radiation (PAR) above maize canopies using sensors from SunScan© Canopy Analysis System (Webb et al., 2013). All PAR measurements were conducted at midday on cloudless days over maize canopies of sampled plots. We made this measurement simultaneously over the canopy of maize under and away from tree canopy, using a Beam Fraction Sensor (BFS) that was wirelessly connected to the main scanner (Fig. 1b). We used the mean of these three measurements for analysis.

2.2.3. Household survey

Each household whose field was selected for data collection was surveyed for socio-economic characterization (Appendix A). Farm-level information such as land holding, family size, livestock holdings and total number of trees on the farms were recorded. The agronomic management of the selected fields such as: land preparation, planting date, fertilization rate, variety used, weeding, and cultivation were recorded, using open-ended questions implemented from the start of seedbed preparation to harvesting. In addition, we used a questionnaire to explore the main rationale of maintaining selected scattered on-farm tree species. First, we appraised this rationale, using semi-structured interviews with key informants and focus group discussions. We identify the 10 most frequently mentioned values of each tree species and quantified the values on a Likert scale with five levels (Gliem and Gliem, 2003). We also quantified the direct economic benefits from trees in the form of charcoal, timber, fencing material and firewood from this survey, using open-ended questions.