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Disentangling the positive and negative effects of trees on maize performance in smallholdings of Northern Rwanda

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ABSTRACT

In the sub-humid parts of East Africa, high population density and pressure on land have led farmers to integrate multipurpose trees on farm. Although mixing trees and crops generates numerous benefits (e.g., fuelwood, timber), it often reduces crop yields. Whereas the effects of mature trees on crops are well studied in semi-arid parklands, there are only few studies for the sub-humid environment. The effects of mature *Alnus acuminata* (Kunth) and *Markhamia lutea* (Seem.) on crops were studied on-farm for four seasons in the sub-humid environment of northern Rwanda. Five sampling points for *A. acuminata* and *M. lutea* were: (i) 1 m from tree trunk without maize, (ii) 3 m from tree trunk without maize, (iii) 1 m from tree trunk with maize, (iv) 3 m from tree trunk with maize and (v) sole maize away from any tree. Nutrient availability and uptake, soil water, air temperature, solar radiation, crop growth and yields were measured. The APSIM-maize module was used to assess the sensitivity of maize yields to changes in these variables. Nutrients availability was higher under *A. acuminata* compared with *M. lutea*, because of higher litter fall but maize nutrient uptake increased only under *A. acuminata* 3 m from tree trunk during a wetter season. None of tree species affected water availability for maize in the topsoil. Photosynthetically active radiation (PAR), total solar radiation and day air temperature were reduced by both tree species. Maize crop at 1 m and 3 m from the tree trunk was shorter in height but had the same number and size of leaves when compared to sole maize plots. Crop yield was generally reduced more at 1 m than at 3 m from the tree trunk. A positive interaction between *A. acuminata* and maize was only apparent at 3 m from the tree in one of the four seasons following higher litter fall, suggesting that the negative effect of shade was offset by extra N input during that season. In a modelled scenario under low N fertilization, larger N input from trees could compensate for yield loss caused by reduction in radiation and temperature in about 60% of the seasons. Our findings suggest that adequate pruning and high leaf litter recycling can reduce the negative effect of shade in low intensity farming systems.

1. Introduction

Trees play a crucial role in rural Africa providing products – such as firewood, timber, fodder, and fruits (Ndayambaje et al., 2013) – as well as services – such as shade, erosion control and maintenance of soil fertility (Buresh, 1998; Sileshi et al., 2014). The demand for tree products and the expansion of agricultural land in Africa has led to deforestation (Barbier, 2004) and shortage of tree products in densely populated countries. In the highlands of East Africa, the dense population has cleared forests leading farmers to integrate trees on farms of ever decreasing size (Allen and Barnes, 1985; Ndayambaje and Mohren, 2011). The pressure on land availability also led farmers to cultivate steeply sloping areas, sometimes with grades exceeding 60%; this leads to risks of severe soil erosion which could be alleviated by trees. As a result, tree density decreased in forests, but increased on farms (Cooper and Krah, 1996; Garrity, 2012). Thus, improving knowledge on the way on-farm tree species affect crop productivity and designing solutions to overcome the challenges of below and above ground competition is highly relevant (García-Barrios and Ong, 2004).

When trees and crops are mixed, tree competition for light, nutrients and water reduces crop yields, while rings of soil fertility around trees may be observed when fields are nutrient deficient (Buresh and Tian, 1997; Kho, 2000; Rao et al., 1997). Hundreds of different nitrogen fixing leguminous trees are used in agroforestry (Giller, 2001) and their N_2-fixing ability can significantly reduce competition for this resource (García-Barrios and Ong, 2004). In East Africa, the effect of several

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different tree species such as *Grevillea robusta* (Lott et al., 2000) and *Eucalyptus* spp. (Mugunga, 2016; Tadele and Teketay, 2014) on crop growth has been studied. However, there is limited information on the effects on crops grown under *Alnus acuminata* (Kunth) (Muthuri et al., 2005) or *Markhamia lutea* (Seem.). These two species are often present in agroforestry systems in East Africa (Okorio et al., 1994), and are dominant in the humid highlands of Rwanda (Mukuralinda et al., 2016).

A. acuminata, a nitrogen fixing tree (Carú et al., 2000) can have beneficial effects on crop yield (Muthuri et al., 2005; Okorio et al., 1994; Peden et al., 1993) and soil water availability for crops (Siriri et al., 2013). On the other hand, *M. lutea* was found to reduce crop yield (Okorio et al., 1994) although it did not strongly compete for soil water due to its slow growth (Radersma and Ong, 2004; Yamoah et al., 1989). Yet, Wajja-Musukwe et al. (2008) found that *A. acuminata* reduced yield more than *M. lutea* despite the latter having more roots in the surface soil layers. It is commonly known that the competitive effects of trees tend to increase as trees mature and causing a concomitant decrease in the yields of the associated crops (Srinivasan et al., 1990). Nevertheless, these studies investigated the effects of only young trees (up to 3 years old) on crops. Although the effects of mature trees on crops are well studied in arid and semi-arid parklands (Ong and Leakey, 1999), there are no equivalent studies in sub-humid environments where *A. acuminata* and *M. lutea* are commonly found (Okorio, 2000).

This study aims to unravel the processes involved in tree-crop interactions in sub-humid environment to inform management and produce recommendations that minimize negative effects and maximize positive effects. Our specific objectives were to quantify the effects of mature *A. acuminata* and *M. lutea* on microclimate and resources available to maize crops grown at varying distances from the tree trunk, and to assess how these effects interact. It was hypothesized that the improvement of soil fertility by the trees could compensate the negative effects of shade in these farming systems where little mineral fertilizer is used.

2. Material and methods

2.1. Study area

The study area is located in Rubavu district, Nyakiliba sector, Gikombe cell, Kitarindwa village in North West of Rwanda in the Birunga agricultural zone, between 1° 40′ 27″ and 1° 41′ 08″ latitude South, and 29° 21′ 28″ and 29° 21′ 10″ longitude East. The elevation ranges from 1941 to 2024 m above sea level. The area receives annual rainfall varying between 1300 and 1600 mm (Verdoodt and Ranst, 2003), distributed over two cropping seasons: the "long rains" from mid-February to mid-July (referred to as season B) and a "short rains" from September to January (referred to as season A), with largest amounts of precipitation in the months of April and November. The soils in this area are typically Mollic Andosols (Verdoodt and Ranst, 2003) which are formed on volcanic deposits and have high organic matter content. Selected sites had soil depth ranging from 100 to 150 cm and a gentle slope ranging from 2 to 6% at the bottom of Gishwati hills.

2.2. Experimental design

A total of six experimental sites − three for *A. acuminata* and three for *M. lutea* − were selected in farmers' fields, based on the presence of two quasi identical trees and an open (treeless) field nearby. All fields were previously cropped with climbing beans and fertilized with manure, except for one field with *A. acuminata* and one field with *M. lutea* and maize which were intercropped with cabbages and onions and fertilized with inorganic fertilizers.

At each experimental site three plots were established: a plot with tree and maize, a plot with sole maize, and a plot with sole tree. Each plot was 10 m by 10 m in size. In the tree-maize plot, maize phenology, morphology, biomass and yield were recorded at distances of 1 m and 3 m from the trunk. The same measurements were done in the sole maize plot, located at least 40 m away from any tree. Thus, the experiment included the following five sampling points for *A. acuminata* (Al) and *M. lutea* (Ma):

- Al–1 m and Ma-1m: 1 m from the tree trunk of sole trees
- Al–3 m and Ma-3m: 3 m from the tree trunk of sole trees
- AlM–1 m and MaM-1m: 1 m from the tree trunk in plots of trees associated with maize
- AlM–3 m and MaM-3m: 3 m from the tree trunk in plots of trees associated with maize
- AlM–40 m and MaM-40m: sole maize, at least 40 m away from any tree

The experiment ran from September 2013 to July 2015, and included two short rainy seasons (2014 A, 2015 A) and two long rainy seasons (2014 B, 2015 B). The maize variety PAN691 was used at a spacing of 0.43 m within rows and 0.9 m between rows with two plants per hill and planted on raised beds. Recommended fertilizer rates were used: 100 kg ha^{-1} of diammonium phosphate applied as basal fertilizer at planting and 100 kg ha^{-1} of urea applied as topdressing 5 weeks after emergence. Trees were managed to produce single stems and lower branches were pruned annually to maintain a canopy of 3.5 m above the ground, according to common local practices (Fig. 1).

2.3. Measurements

For each plot, composite soil samples were systematically taken at the on-set of the experiment in 12 quadrats starting from the centre of the plot at three depths (0–20, 20–40, and 40–60 cm). Each plot sample

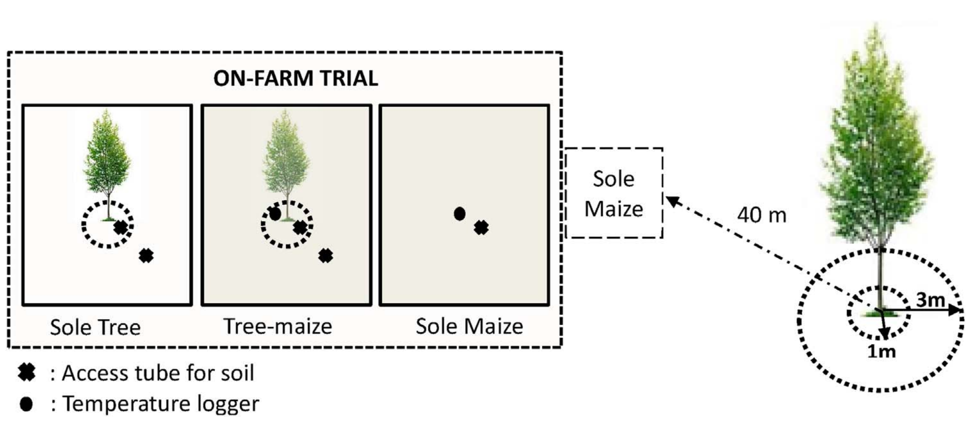

Fig. 1. Experimental design with treatments in 10 by 10 m plots and illustration of concentric measurement at 1, 3 and 40 m distance from the tree trunk.