Europ. J. Agronomy 86 (2017) 78–86

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Tree-crop interactions in maize-eucalypt woodlot systems in southern Rwanda

C.P. Mugunga[a,c,*], K.E. Giller[b], G.M.J. Mohren[c]

[a] Forestry and Nature Conservation Department, College of Agriculture, Animal Sciences and Veterinary Medicine, University of Rwanda, Huye Campus, P.O. Box 56, Butare, Rwanda
[b] Plant Production Systems, Wageningen University, P.O. Box 430, 6700 AK, Wageningen, The Netherlands
[c] Forest Ecology and Forest Management Group, Wageningen University, P.O. Box 47, 6700 AA Wageningen, The Netherlands

A R T I C L E I N F O

Article history:
Received 19 October 2016
Received in revised form 2 March 2017
Accepted 13 March 2017

Keywords:
Eucalyptus woodlots
Environmental resources
Agroforestry system
Tree-crop interface

A B S T R A C T

We studied the interaction between *Eucalyptus saligna* woodlots and maize crop in southern Rwanda. Three sites were selected and in each, a eucalypt woodlot with mature trees and a suitable adjoining crop field of 12.75 m × 30 m was selected. This was split into two plots of 6 m × 12 m and further subdivided into nine sub-plots running parallel to the tree-crop interface. Maize was grown in both 6 m × 12 m plots and one of these received fertiliser. Soil moisture, nutrients and solar radiation were significantly reduced near the woodlots, diminishing grain yield by 80% in the 10.5 m crop-field strip next to the woodlot. This reduction however affects only 10.5% of the maize crop field, leaving 89.5% unaffected. Spreading the loss to a hectare crop field, leads to an actual yield loss of 0.21 t ha^{-1}, equivalent to 8.4%. Expressing yield loss in tree-crop systems usually presented as a percentage of yield recorded near the trees to that obtained in open areas may be misleading. Actual yields should be reported with corresponding crop field areas affected. Variation in grain yield coincided with those for soil moisture, soil N and K; all increasing from the woodlot-maize interface up to 10.5 m and remaining similar to the values in open areas thereafter. Solar radiation continued to increase with distance up to 18 m from the woodlot-maize interface. Harvest index in unfertilised maize exceeded that in the fertilised treatment reflecting the crop's strategy to allocate resources to grain production under unfavourable conditions. Fertilisation increased maize yield from 1.3–2.6 t ha^{-1} but the trend in the woodlot effects on maize remained unaltered.

1. Introduction

Steady population growth in the tropics has led to an increased demand for agricultural products and for timber and fuelwood. In the eastern and central African highlands, this wood demand has bypassed the capacity of forest to supply wood, and has resulted to the degradation of many natural forests (Burnett, 1985; Thorhaug and Miller, 1986). A possible means to reduce pressure on natural forests and meet the wood and food demand is to include trees in the farming systems (Chamshama, 2011). To provide fuelwood and timber, establishment of eucalypt plantations was promoted since the colonial era (Munyarugerero, 1985). *Eucalyptus* was widely adopted, and in 2008, 64% of the total plantation area (102,800 ha) in Rwanda was covered by eucalypts (Nduwamungu et al., 2008). Most of the plantations are owned by local governments (65% of the area), followed by smallholder farmers (26%) and private institutions (9%). The plantations mainly consist of small woodlots and occur in all ecological zones, with more plantations in the southern and western Provinces (Nduwamungu et al., 2008).

Food production is limited by the availability of land for annual crops (Hauser, 2006). A continuous growing population led in Rwanda to land fragmentation and small average land holdings per household of around 0.5 ha (Bucagu et al., 2014; Mpyisi et al., 2003). The urge to be self-sufficient in wood products drives farmers to grow trees on their farms. As a result, small crop fields and eucalypt woodlots are intermixed in a mosaic in the landscape. Because of the proximity of crops and trees, and the tree-crop interactions, this can be classified as an agroforestry system, containing some features of short-rotation woodlots.

In agroforestry systems, trees and crops are commonly grown in different spatial arrangements where trees provide various benefits to the crops. Windbreaks for example are beneficial to crops,

* Corresponding author at: Forestry and Nature Conservation Department, College of Agriculture, Animal Sciences and Veterinary Medicine, University of Rwanda, Huye Campus, Box 56, Butare, Rwanda.
E-mail addresses: mugungacp@gmail.com (C.P. Mugunga), ken.giller@wur.nl (K.E. Giller), frits.mohren@wur.nl (G.M.J. Mohren).

http://dx.doi.org/10.1016/j.eja.2017.03.004
1161-0301/

Table 1
Tree sizes in terms of diameter at breast height, total tree height and the above ground biomass recorded in the three *Eucalyptus saligna* woodlots in eucalypt-maize agroforestry systems in southern Rwanda.

Site	[a]M	Density (Stems ha^{-1})	Breast height diameter (cm)			Total tree height (m)			Total dry matter (kg $tree^{-1}$)		
			min	max	mean	min	max	mean	min	max	Mean
Cyarwa	1	970	15.1	24.8	19.8	15.0	23.2	18.6	116.5	376.4	268.8
Mukura II	1	420	20.7	32.6	26.5	19.4	29.3	24.4	361.3	575.2	432.3
Save I	0	651	19.0	28.0	22.5	18.1	28.2	24.9	274.7	498.2	363.5

[a] Management practice 1 = coppice and 0 = planted stands.

especially in dry areas where they are useful for the control of wind erosion, soil conservation, and the amelioration of the microclimate (König, 1992; Mayus et al., 1999). Trees grown in hedgerow intercropping systems may improve soil conditions through nitrogen fixation and increase crop yield (Akyeampong et al., 1995). However, trees also compete with crops for environmental resources and their negative effects may outweigh the potential benefits (Rowe et al., 2005).

Eucalyptus trees may be such a mixed blessing; they are fast growing even on marginal sites, produce a wide range of valuable products in short periods, are easy to manage and can be coppiced several times giving several yields at one planting (Casson, 1997). They are however, known to be especially competitive, and to significantly reduce productivity of companion plants. They may severely compete with crops for soil moisture (Kidanu et al., 2005) and soil nutrients (Harrison et al., 2000), and are thought to have allelopathic effects on crops growing in their vicinity (Lisanework and Michele, 1993).

Low crop yields are common on the highly weathered and nutrient poor soils of the study area (Rushemuka et al., 2014), constraining food production and food security. Although food security has been improving significantly in Rwanda, 21% of households were still food insecure in 2012 (WFP, 2012). The dominance of eucalypt woodlots in the agricultural landscape calls for a need to better understand the effects of the trees on crop production and food insecurity. The woodlots are expected to influence crop production in the agroforestry systems. Relevant studies have been done in tropical countries (Kidanu et al., 2005; Sudmeyer and Hall, 2015). However, these studies evaluated the effects of the spatial arrangement of tree lines rather than the effects of the woodlots. The latter is the most common in Rwandan farming systems.

The aim of this study is to analyse the eucalypt woodlot-maize system, and to quantify how resource availability (water, nutrients and light) and crop performance (height growth, stover production and grain yield) vary with the distance from the eucalypt woodlots. Fertilization was added to analyse whether eucalypts and maize mainly compete for nutrients, and whether fertilization can mitigate for the negative woodlot effects.

2. Methods

2.1. Site description

Three sites were selected in southern Rwanda, with two (Cyarwa and Mukura) located in the periphery of Butare town, Huye district, and the other (Save) in the neighbouring district of Gisagara. More specifically, Cyarwa is located at 2.61591S and 29.76660E at 1655 m asl elevation; Mukura at 2.64804S and 29.73008E with the elevation of 1667 m asl and Save at 2.57384S and 29.77603E and 1694 m elevation. According to the agro-ecological classification defined by Delepièrre (1975), the sites are located in the central plateau and hills zone of Rwanda. The area has a mean annual rainfall of 1200 mm y^{-1}; mean annual temperature of 21 °C and the soils are derived from granitic rocks and are classified as ferralsols in the hills (Birasa et al., 1990).

The choice of sites and study woodlots was based on the presence of a woodlot with mature trees of *Eucalyptus saligna*, with an adjacent crop field. One woodlot was selected in each of the three sites. To ensure representative coverage of the study zone, the three sites used were located at least five km apart.

Maize Katumani variety was grown in the crop fields adjacent to *Eucalyptus* woodlots. The woodlot was located on the eastern side of the crop fields in two sites (Cyarwa and Mukura) and on the northern side of the crop field in the Save site.

2.2. Experimental design and field procedures

The experiment was conducted in three consecutive seasons, that is, from January-May and September-December 2007 and January-May 2008. Characteristics of the woodlots used are provided in Table 1. In each of the three experimental sites, three crop field replications adjoining one *E. saligna* woodlot were selected and crop plots of 12.75 m × 30 m were pegged. Each replication was split into two smaller plots of 6 m × 30 m separated by 0.75 cm, a space equal to the interline spacing; and further subdivided into subplots with the following dimensions running parallel to the tree-crop interface into the farmland: 0–2, 2–4, 4–6, 6–9, 9–12, 12–16, 16–20, 20–25 and 25–30 m. One of the two 6 m × 30 m plots received NPK composite fertiliser at a rate of 300 kg ha^{-1}, equivalent to 36 kg of N, 4 kg of P and 5 kg of K per hectare. Sites were tilled manually and sown with maize on 25 February 2007 in the first season, on 30 September 2007 in the second season and on 26 January 2008 in the third season.

Abnormally little and erratic rains in the first season led to poor establishment and the experiments were replanted at the end of March 2007. The spacing was 0.5 m between plants and 0.75 m between lines. Three maize seeds were sown per hole and these were later thinned to leave two plants per hole. The plots that received fertiliser at sowing were top dressed with an N based urea (46%) at the rate of 100 kg ha^{-1} (MINAGRI, 2000). To avoid edge effects, two guard (outer perimeter) rows were not considered for assessment, leaving the six innermost maize rows in each subplot for evaluation. It was assumed that the effect of trees did not extend as far as 25 m from the tree-crop interface; the farthest sub-plot located at 25–30 m from eucalypt woodlot was therefore taken as a control.

2.3. Data collection and analyses

Maize traits studied included growth (height and biomass) and grain yield. Field procedures for each item is described below but in principle, all measurements were done in the nine subplots explained above. For solar radiation, an extra location was added at 5 m inside the woodlot from the tree-crop interface to capture the light intensity under the woodlot canopy.