Field Crops Research 221 (2018) 238–244

Contents lists available at ScienceDirect

Field Crops Research

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

Conservation agriculture with trees amplifies negative effects of reduced tillage on maize performance in East Africa

Alain Ndoli[a,b,⁎], Frédéric Baudron[b], Tesfaye Shiferaw Sida[a,b], Antonius G.T. Schut[a], J. van Heerwaarden[a], Ken E. Giller[a]

[a] Plant Production Systems, Wageningen University, PO Box 430, 6700 AK Wageningen, The Netherlands
[b] CIMMYT- Southern Africa Regional Office, PO Box MP163, Mt Pleasant, 25 km Peg Mazowe Road, Harare, Zimbabwe

ARTICLE INFO

Keywords:
Maize
Minimum-tillage
Crop phenology
Equatorial savannah

ABSTRACT

Conservation agriculture (CA) is widely promoted in sub-Saharan Africa both in open fields and in agroforestry where the practice is known as 'conservation agriculture with trees' (CAWT). Although advantages and disadvantages of CA are well studied under sole cropping, less is known about its impact in agroforestry systems. The performance of open pollinated maize varieties under CA, CAWT, sole maize under conventional tillage (CT) and conventional tillage with trees (CTWT) was compared on-farm in equatorial savannah areas over four consecutive seasons in Rwanda and two seasons in Ethiopia. The tree species considered in the study were mature *Grevillea robusta* (A. Cunn.) and *Senna spectabilis* (DC.) in Rwanda and mature *Acacia tortilis* (Forssk.) in Ethiopia. Both CA and the presence of trees consistently reduced maize emergence, leaf area (LA), plant height, and maize yields. Crop emergence was significantly reduced under CAWT compared with CTWT. Maize emergence rates in CAWT and CTWT were respectively 46.9% and 70.1%, compared with 74.7% and 79.8% in sole maize under CA and CT. Grain yield in CAWT and CTWT were respectively 0.37 t dry matter (DM) ha^{-1} and 1.18 t DM ha^{-1} as compared with 1.65 t DM ha^{-1} and 1.95 t DM ha^{-1} in CA and CT. We conclude that CAWT strongly reduces crop yield in the equatorial savannah of East Africa. CA is incompatible with agroforestry under the conditions of our study. There is an urgent need for rigorous research to revisit if, when and where CAWT can generate benefits for smallholder farmers.

1. Introduction

Agroforestry, the association of annual crops and trees, is an option advocated to increase crop production sustainably in sub-Saharan Africa where the use of external inputs is low (Pretty et al., 2011; Robert and Peter, 1987). Although agroforestry may sustain crop productivity on the long-term, an important concern is its negative impact on crop yield in the short-term in semi-arid tropics, because of above-ground competition for light (Rao et al., 1997) and below-ground competition for water and nutrients between crops and trees (Ong et al., 1991; Radersma and Ong, 2004). Most published work has focused on above-ground tree management, such as pruning regimes (Mugunga et al., 2017; Rao et al., 1997), while below-ground management of tree roots was seldom considered. Recent studies exploring options to increase crop yield in agroforestry systems have recommended pruning of tree roots to limit nutrient and water competition between trees and crops in semi-arid areas (Bayala et al., 2015; Muthuri et al., 2005). Beyond tree pruning, improved soil management options could be explored to optimize crop productivity in agroforestry systems (Guto et al., 2012; Hulugalle and Ndi, 1993).

Conservation agriculture (CA) is a set of principles for resource-efficient agricultural crop production based on three principles: (1) minimum soil disturbance; (2) permanent organic soil cover (consisting of a growing crop or a dead mulch of crop residues); and (3) diversified crop rotations, in particular including legumes (www.fao.org/ag/ca). CA has been reported to increase and stabilize maize yields, conserve soil moisture, increase soil carbon stocks, and improve soil physical and chemical properties (Rockström et al., 2009).

Kassam et al. (2009) reported that CA and agroforestry practices have many features in common, such as increased ground cover and incorporation of legumes in the system. They stated that both crops and trees would benefit from minimum soil disturbance, and that CA and agroforestry when combined would have synergistic effects on soil health and crop productivity. Combining CA with agroforestry was recommended as a sustainable approach to the production of food, fodder, fuel, fibre and income from intercropped trees while restoring

⁎ Corresponding author at: Plant Production Systems, Wageningen University, PO Box 430, 6700 AK Wageningen, The Netherlands.
E-mail address: alain.ndoli@wur.nl (A. Ndoli).

https://doi.org/10.1016/j.fcr.2018.03.003
Received 6 September 2017; Received in revised form 1 March 2018; Accepted 2 March 2018
Available online 23 March 2018

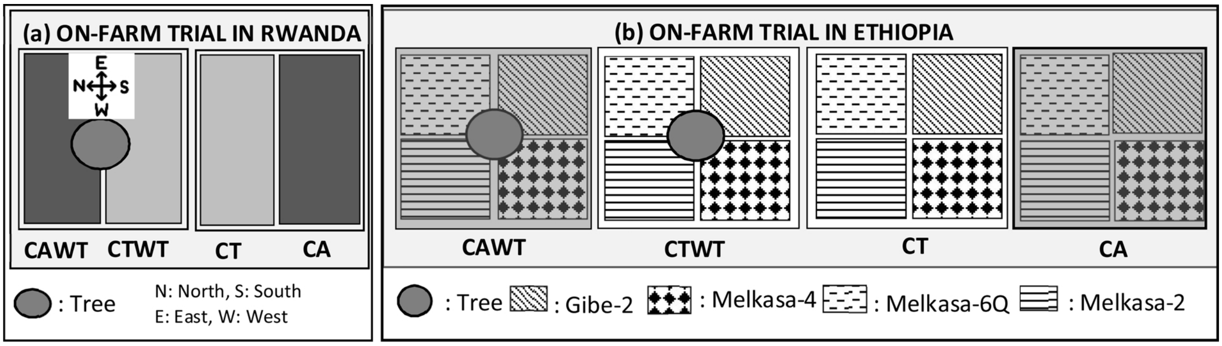

Fig. 1. Layout of the experiments in Bugesera, Rwanda (a) and in Meki, Ethiopia (b) comparing conventional tillage in sole maize (CT), conservation agriculture in sole maize (CA), conservation agriculture with trees (CAWT) and conventional tillage with trees (CTWT) for one open pollinated maize cultivar in Rwanda and four open pollinated maize cultivars in Ethiopia.

exhausted soils (Garrity et al., 2010). In this review, the authors cite the example of Zambian farmers (Haggblade and Tembo, 2003) cultivating maize under CA and with *Faidherbia albida* trees incorporated in the system at a density of 100 trees per hectare, and later thinned gradually down to 25 trees per hectare who benefited from an extra 1.1 t ha^{-1} maize when compared with conventional farming (ox-ploughing with no trees in the system). A fresh approach – conservation agriculture with trees (CAWT) – was coined by combining CA with agroforestry (Ngrsquo et al., 2013). To date, the sparse information on CAWT is presented in project reports, extension materials and personal communications, apart from a few survey results.

Although advantages and disadvantages of CA are well documented under sole cropping (Chivenge et al., 2007; Giller et al., 2009; Rockström et al., 2009), less is known about its impact in agroforestry systems despite the promotion of CAWT in many developing countries (Mutua et al., 2014). We hypothesize that CAWT reduces crop yields by exacerbating below-ground competition for water and nutrients. We assessed the performance of sole maize under conventional tillage (CT) and CA, as well as maize with trees under conventional tillage (CTWT) and CA (CAWT) in two equatorial savannah regions of East Africa. Common open pollinated maize varieties were used. The tree species considered were *Grevillea robusta* (A. Cunn.) and *Senna spectabilis* (DC.) in Rwanda and *Acacia tortilis* (Forssk.) in Ethiopia. The experiment was conducted on-farm during four consecutive seasons in Rwanda, and two consecutive seasons in Ethiopia.

2. Material and methods

2.1. Site characteristics

Experiments were conducted in two locations: Bugesera in Rwanda and Meki in Ethiopia. Both are classified as semi-arid in the national systems with a Köppen-Geiger classification “equatorial savannah with a dry winter” (Kottek et al., 2006). Bugesera is located at 2° 21′ S, 30° 15′E, at an elevation of about 1400 m above sea level (a.s.l). The climate is characterized by a bimodal rainfall pattern with primary and secondary peaks in April and November, respectively. The first harvest is in January/February, after the “short rains” from September to January (season A), and the second harvest is in August, after the “long rains” (season B) from mid-February to mid-July. Annual rainfall varies between 850 and 1000 mm per year with an average annual temperature of about 21 °C (Verdoodt and Ranst, 2003). Soils are humic Ferralsols at lower and haplic Ferralsols at higher landscape positions with soil depths of about 100–200 cm (Verdoodt and Ranst, 2003). This region is characterized by large densities of termites which accelerate turnover of crop residues and consume tree bark (Balasubramanian and Sekayange, 1991; Musebe et al., 2017). The selected plots were cropped with maize or sorghum in rotation with bush beans in previous seasons.

In Ethiopia, experiments were carried out in Meki, in the lowlands of the Central Rift Valley located at 8°11′N, 38°51′E and an elevation of about 1500 m a.s.l. The agroecology is classified as equatorial savannah with a dry winter (Kottek et al., 2006). The rainy season or “*Kiremt*” normally runs from June to September with an annual total rainfall ranging from 281 to 1131 mm with a long-term average of 729 mm per year (Getachew and Tesfaye, 2015). The average annual temperature is about 19.3 °C. Soils are predominantly deep Andosols. The selected plots were previously cropped with maize. Two automatic weather stations (Vantage Pro2™ Davis Instruments Corp, USA) one in Rwanda and one in Ethiopia were installed within 1 km of all plots to measure the daily rainfall.

2.2. Experimental layout

Experiments compared maize crops under CT, CA, CTWT and CAWT during the 2015 A, 2015 B, 2016 A and 2016 B seasons in Rwanda and during the 2014 and 2015 seasons in Ethiopia. Mature *G. robusta* and *S. spectabilis* trees were selected in Rwanda and mature *A. tortilis* trees in Ethiopia. These tree species were selected based on their abundance in farmers’ fields compared with other agroforestry tree species. Tree height, diameter at breast height (DBH), diameter at stump height (DSH; i.e., at 10 cm from the ground), and canopy radius were measured and tree age was assessed from farmer recall. Three farms were selected per tree species. In Rwanda, for each farm included in the experiment, one plot with a tree in the centre and one plot in an adjacent open field were selected. The plot size was 10 × 10 m, and each plot was split into two subplots of 5 × 10 m; one managed under CT and the other under CA (Fig. 1a). Plots and planting lines were oriented from East to West to allow similar shading effect on the CAWT and CTWT subplots. In Ethiopia, there were four plots per selected farm: two plots were located under almost identical trees and two control plots in an open field. One plot with tree and one control plot in open field were managed under CA while the other plot with tree and the other control plot in open field were managed under CT. The plot size was 10 × 10 m, but here plots were split into four subplots to accommodate four open pollinated maize varieties (OPVs) (Fig. 1b). Unfortunately, one replicate in the Ethiopian experiment was damaged by livestock and was excluded from the analysis.

In Rwanda, the most frequently used OPV cultivar i.e., ZM607 was used in all plots (Fig. 1a). In Ethiopia, the selected OPVs were Gibe-2, Melkasa-4, Melkasa-6Q and Melkasa-2 and these were randomly assigned to the four subplots per treatment each season, controlling for differences between the subplots (Fig. 1b). Maize was sown with a spacing of 0.4 m within rows and 0.8 m between rows with two seeds per station in Rwanda. In Ethiopia, maize was sown at a spacing of 0.3 m within rows and 0.7 m between rows with 1 plant per station left after thinning.

In the CA and CAWT treatments, seeds were sown after slashing weeds with a sickle, without prior land preparation. No crop residues