European Journal of Agronomy 99 (2018) 148–155

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Quantifying nutrient deposition and yield levels of maize (*Zea mays*) under *Faidherbia albida* agroforestry system in Zambia

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ARTICLE INFO

Keywords:
Faidherbia albida
Nutrient deposition
Organic carbon
Maize yield
Agroforestry

ABSTRACT

Inherently low soil fertility and costly chemical fertilizers contribute to low maize yield and food insecurity among rural smallholder farmers in sub-Saharan Africa. The use of fertilizer trees such as *Faidherbia albida* (*Faidherbia*) to improve the soil fertility and yield of maize is recognized by many as a good practice. This study examined the litterfall pattern, quantity, and nutrient deposition from 8-, 15- and 22-year old *Faidherbia* trees at two locations in Zambia before and during the 2014/15 and 2015/16 rainy seasons. Litterfall including its nutrient content was estimated using nylon mesh litter traps erected under three randomly selected representative *Faidherbia* trees of each age. Further, we assessed the yield levels of maize grown under 8-, 15- and 22-year old *Faidherbia* trees. All trees started dropping litter before the onset of the rains in both seasons. The leaf litterfall averages of the two seasons were 1.6, 1.7 and 3.8 t DM ha^{-1} from 8-, 15- and 22-year-old trees, respectively. These litterfall quantities translate to potential carbon and nutrient deposition of 0.7–1.6 t C ha^{-1}, 34–83 kg N ha^{-1}, 1.8–4.3 kg P ha^{-1} and 10–26 kg K ha^{-1} per year. The yield levels of maize for the two growing seasons under *Faidherbia* tree canopy were 7–12 times higher than from outside the canopy, and these yield differences were much more pronounced in the driest year (2015/16 growing season). The large nutrient deposition through litterfall and increase in maize yield under *Faidherbia* tree canopies show the potential of these trees to contribute to food security and mitigate the risk of crop failure on resource-poor smallholder farmers' fields, especially in drought years.

1. Introduction

Maize (*Zea mays*) is the most important food crop in Zambia that has been commercialized as a cash crop by many rural smallholder farmers (Jayne et al., 2007). Despite the availability of improved maize seed varieties with a yield potential of 7-10 t ha^{-1}, many smallholder farmers rarely reach a yield of 1.2-1.5 t ha^{-1} (FAO, 2016; Xu et al., 2009). Poor agricultural practices such as limited (8–20 kg N ha^{-1}) or no nutrient replacement, and crop residue removal, thereby exposing fields to erosion, are common on most smallholder farmers' fields in sub-Saharan Africa (SSA), Zambia included (Morris et al., 2007; Murithi et al., 1994). These practices reduce the productivity of already fragile soils and severely increase the already high food insecurity among rural smallholder farmers. Therefore, alternative low-cost practices that could enhance soil fertility and improve yield levels of maize among smallholder farmers in Zambia are much needed.

One such alternative practice is agroforestry. Fertilizer trees in agroforestry have shown the potential to conserve soil organic carbon (SOC) and replenish soil fertility through root and litter decomposition (Schroth and Sinclair, 2003; Akinnifesi et al., 2010). Mafongoya et al. (2006) describe a fertilizer tree system as one that restores nutrient cycling and replenishes soil fertility through the on-farm management of nitrogen-fixing trees. The promotion of fertilizer trees among smallholder farmers is based on their ability to address most of the biophysical and socioeconomic limitations identified with earlier practices such as green manures (Kwesiga et al., 2003; Akinnifesi et al., 2008).

Faidherbia albida (Del.) A. Chev. (syn. *Acacia albida*) (*Faidherbia*) is being promoted in Zambia to improve soil fertility and crop yields on smallholder farmers' fields. Because of its unique characteristic of shedding leaves during the wet season and having them in the dry season, crops are grown under the canopy with minimum shading. The benefits of having this tree in a cropping system are (1) increase in crop yield under the canopies, (2) improvement of soil quality underneath the canopies, and (3) addition of biomass through litterfall (Akinnifesi et al., 2010). Apart from its use in agriculture, *Faidherbia* trees provide

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https://doi.org/10.1016/j.eja.2018.07.004
Received 21 April 2017; Received in revised form 27 June 2018; Accepted 13 July 2018
1161-0301/

wood for construction and firewood to the rural households, shade to animals during the hot dry season and the pods from the trees are a good source of livestock feed (Phombeya, 1999).

Much of the research in Zambia has been on 'mature' trees, usually > 35 years old (GART 2009; Shitumbanuma, 2012). However, Wahl and Bland (2013) observed that due to the promotion of the tree, there is an increasing share of young *Faidherbia* trees, ranging from seedlings up to an age of 25 years on many smallholder farmers' fields in Zambia. The benefits that are attributed to 'mature' trees possibly differ from relatively young trees. Litterfall production and quality may vary with tree size, tree age, climate, soil type and management practice (Starr et al., 2005; Murovhi et al., 2012; Negash and Starr, 2013). Litterfall has been documented by many researchers as one of the major sources of nutrients and SOC through which soils are improved under canopies of *Faidherbia* trees (Saka et al., 1994; Kamara and Haque, 1992; Umar et al., 2013). Even so, information on litterfall pattern and quantity from *Faidherbia* trees and relating this to how much nutrients are added by the trees on smallholder fields in SSA is either inadequate or lacking. To the best of our knowledge, no studies have been conducted on litterfall patterns and nutrient deposition from different ages of *Faidherbia* trees in SSA.

Therefore, we conducted a study to estimate litterfall patterns and nutrient deposition from different age classes of *Faidherbia* trees in Zambia. We hypothesized that: (1) litterfall from *Faidherbia* trees supply substantial amounts of nutrients (N,P,K) for maize production, (2) nutrients (N,P,K), total N, and SOC are higher in soils under *Faidherbia* tree canopies than outside the canopies, and (3) the maize yields under *Faidherbia* tree canopies of varying ages are consistently higher compared with yield outside the tree canopies. To test these hypotheses, we estimated litterfall including its nutrient content of three age classes of *Faidherbia* trees. Further, we measured the soil characteristics of soils collected under *Faidherbia* canopies and outside the tree canopies. Finally, maize was used as a response crop to compare yields under the canopies of three ages of *Faidherbia* trees with respective yields outside the canopies.

2. Materials and methods

2.1. Study area and tree selection

The study was conducted at Kasisi Agricultural Training Center (Kasisi) in Chongwe District of Lusaka Province and Golden Valley Agricultural Research Trust (Chisamba) in Chisamba District of the Central Province of Zambia. The locations are in agro-ecological region II of Zambia, which receives between 800–1000 mm average annual rainfall. Monthly rainfall distribution for the study sites was measured (Fig. 3). The field in Kasisi has sandy loam texture and the field in Chisamba has clayey texture in the upper 20 cm soil layer.

We selected the fields for sampling based on: (1) presence of six or more isolated trees, (2) trees of similar size and age, and (3) trees on uniform soil texture and topography within the site. Trees at Chisamba were of two age groups namely: 8-year old trees on a 1 ha field and 15-year old trees on a 6.5 ha field planted in a grid spaced at 10 m x 10 m. Trees at Kasisi were 22-years old and planted as hedge trees with an average within-hedge spacing of 10 m. Some trees within the hedge at Kasisi were larger than others, therefore, the canopies of the big trees overlap with smaller trees. The age of trees mentioned here are those at the time of setting up the experiment (2014) and for simplicity, these ages will be used throughout the paper.

2.2. Experiment setup and sampling

2.2.1. Soil sampling

Three *Faidherbia* trees per age were selected randomly for soil sampling. Each tree was taken as a replicate, and quadrants under the tree canopy centered on the tree trunk were made on the ground. Soil samples from 0–20 cm soil layer were collected from five random points within each quadrant (under the canopy) using a soil auger, and thoroughly mixed to make a composite sample (Fig. 1). Soil samples outside the canopy (controls) were collected randomly in 3 replicates (five sampling points per replicate) more than 5 m from the edge of the canopy on the windward side of the tree (Fig. 1). Soil samples outside the tree canopies at Chisamba were collected more than 10 m from the two fields as the area immediately surrounding the trees was used for other research activities. We used only one control (3 replicates) for the two ages at Chisamba because the trees are on the same soil texture and under the same management. All soil samples for characterization were collected before the start of the rains in 2014/15 growing season.

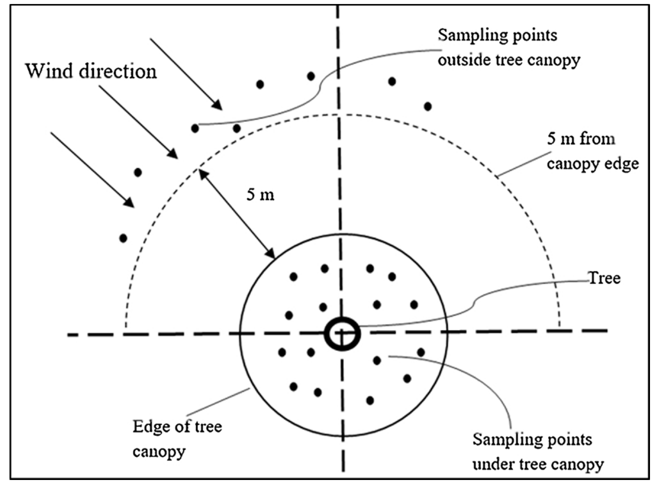

Fig. 1. A schematic representation of the soil sampling campaign.

Air-dried soils for soil chemical and physical characteristics analysis were passed through a 2 mm sieve. Soil texture was determined by the hydrometer method as outlined by Gee and Bauder (1979). The soil pH in 1 M KCl was determined from a soil:solution ratio of 1:2.5 using a pH meter (Thermo Orion, model 420A+). SOC and total N concentrations were measured with a Variomax CNS elemental analyzer (Elementar GmbH, Hanau, Germany) using the Dumas method. Plant available K and P were extracted with ammonium lactate (soil:solution ratio 1:20) and quantified using an Inductively Coupled Plasma (ICP) spectrometer (iCAP 6000 series, Thermo Fisher Scientific Inc., Newington, USA). Mineral N (NH_4^+ and NO_3^-) was determined from 20 g soil extracted with 1 M KCl (soil:solution ratio 1:5) and measured colorimetrically with a continuous flow auto analyzer (Chem-lab 4, Skalar 223 Analytical, Breda, The Netherlands) after shaking for one hour.

2.2.2. Litterfall pattern and quantity

We selected three representative trees per tree age group. The tree stem circumference was measured at a height of 1.3 m above ground level. The average tree canopy radius was measured at each cardinal point of the tree with a tape measure from the tree stem to points on the ground judged to be the edge of the canopy (Table 1). The height of the trees was measured using a Suunto Hypsometer (PM-51520PCP, Suunto company, Finland). Under each of the three randomly selected trees, three litter traps with a PVC frame and a square opening of 0.5 m^2 (1.2 mm nylon mesh size) were installed 1 ± 0.02 m above ground in a triangular formation around the tree stem (Fig. 2). The average distances of the litter traps from the tree trunk were 2.4 m, 2.7 m and 6.4 m, for 8-, 15- and 22-year-old trees, respectively. We installed litter traps in the period thought to correspond with highest leaf-shedding for these trees until the trees were leafless. In total, nine litter traps were installed under each age group from August to January in 2014/15, while in 2015/16, this was from August to April in 2015/16. Litter from the traps was collected every two weeks and oven-dried at 65 °C until constant weight. The oven-dried litter was sorted by hand to separate