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# Maize–mucuna rotation: An alternative technology to improve water productivity in smallholder farming systems

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ABSTRACT

Rain-fed crop production systems in the semi-arid tropics of Zimbabwe are characterized by low water productivity (WP), which is partly attributed to inherent low soil fertility, and further exacerbated by continuous cropping without addition of adequate organic and inorganic fertilizers due to unavailability and high costs. A simulation modeling approach was used to evaluate potential interventions that can be used as entry points to improve crop water productivity. Low-cost interventions that use locally available organic inputs were evaluated using the Agriculture Production Systems sIMulator (APSIM). The farmer practice (FP) was compared to interventions comprising manure application (MN) and maize–mucuna rotation (MMR). Their potential effects on crop water productivity, dynamics of soil organic carbon (SOC) and total nitrogen (TN) were assessed. Average maize grain water productivity was 0.32, 0.40 and 0.70 kg $m^{-3}$ under the FP, MN and MMR treatments, respectively, while that of mucuna biomass (*Mucuna pruriens*) was 1.34 kg $m^{-3}$. Cropping under the FP and MN treatments showed negative trends in SOC and TN over 30 years, with average losses ranging from 17 to 74 kg $ha^{-1}$ $yr^{-1}$ and 6 to 16 kg $ha^{-1}$ $yr^{-1}$, respectively. In contrast, the MMR treatment showed positive trends in both soil organic carbon (SOC) and total nitrogen (TN). The SOC and TN increased by 2.6–194 kg $ha^{-1}$ $yr^{-1}$ and 6–14 kg $ha^{-1}$ $yr^{-1}$, respectively. According to the simulation results it can be concluded that the MMR treatment can improve the water productivity of smallholder maize systems in the semi-arid areas of Zimbabwe under nutrient-depleted soil conditions and can also contribute to the building up of SOC and TN.

## 1. Introduction

Crop water productivity (WP) is generally defined as the ratio of crop yield to actual evapotranspiration (Cai and Rosegrant, 2003; Liu et al., 2008), and can be improved by producing the same output with less water or by increasing output with the same amount of water (Mustafa et al., 2008). Grain water productivity of cereal crops in sub-Saharan Africa currently ranges from 0.04 to 0.1 kg $m^{-3}$ while the potential is more than 1.0 kg $m^{-3}$ (Rockström et al., 2003). Similarly, rain-fed crop production systems in the semi-arid tropics of Zimbabwe are also characterized by low WP despite research and extension efforts to develop and popularize improved genetic material and management practices (Ahmed et al., 1997). Low WP is partly attributed to inherent low soil fertility, which is further exacerbated by continuous cropping without addition of adequate organic and inorganic fertilizers due to unavailability and high costs (Nzuma et al., 1998; Mugwe et al., 2004). The challenge is to improve soil fertility and water management in order to increase the productive green water (plant transpiration) use under rain-fed cropping systems (Rockström et al., 2003). Sandy soils are predominant in the smallholder farming systems of Zimbabwe, and these soils are inherently infertile, poorly buffered and contain small amounts of soil organic matter (SOM) (Zingore, 2006). Low SOM is also attributed to high turnover rates caused by the high tropical temperatures and the poor protection offered by sandy soils to microbial attack (Mapfumo and Giller, 2001). Therefore, there is a need to regularly apply external organic inputs.

Alternative sources of soil amendments need to be sought in smallholder farming systems, where soil fertility needs to be rebuilt and where high cost and low supply quantities of inorganic fertilizers limit their application (Omotayo and Chukukwa, 2009). In Zimbabwe, leguminous forage crops such as *Lablab purpureus*, *Mucuna pruriens*, *Medicago sativa*, and *Cajanus cajan* have been introduced as green manure or cover crops to commercial and communal farmers mostly in the sub-humid areas, where cereal crops productivity was improved through provision of alternative low-cost organic fertilizers (Maasdorp and Titterton, 1997; Ngongoni et al., 2007). Grain legumes are also known to improve

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soil fertility, but farmers only grow them on small areas because of their preference for cereal staples, lack of high quality seeds, disease constraints and lack of output markets (Ncube et al., 2008). In contrast, forage legumes, such as mucuna, can be grown on fallow land, seed can be reproduced, and biomass can be used as green manure to improve soil fertility or as livestock feed. Mucuna production has been successfully tested under smallholder conditions on exhausted sandy soils where biomass yield ranged from 2 to 6 t $ha^{-1}$ and up to 10 t $ha^{-1}$ without and with P fertilizer application, respectively (Waddington et al., 2004). Maize grain yield increases of more than 64% have been measured in Zimbabwe after application of mucuna as green manure, where nitrogen (N) contribution from mucuna biomass ranged from 101 to 348 kg N $ha^{-1}$ (Whitbread et al., 2004). In Malawi, maize following mucuna yielded about 1.5 t $ha^{-1}$, while maize under the recommended fertilizer application yielded 2.3 t $ha^{-1}$ and 0.8 t $ha^{-1}$ on unfertilized plots (Sakala et al., 2003). Mucuna is a vigorous twining crop that can grow on sandy soils with low available phosphorus (P) (Cook et al., 2005), and can suppress weeds such as *Imperata cylindrical* and *Striga*, which are some of the most problematic weeds in the depleted sandy soils in most smallholder farming systems (Weber, 1996; Ikie et al., 2006). Natural pasture provides the basic feed for ruminant animal production (Woyengo et al., 2004) *in these systems and* grass biomass and quality is low during the dry season with protein content dropping from 120 to 160 g crude protein (CP) $kg^{-1}$ dry matter (DM) in the growing season to as low as 10–20 CP $kg^{-1}$ DM in the dry season (Baloyi et al., 1997; Maasdorp and Titterton, 1997; Mpairwe, 2005). This causes livestock dry season feed levels to be critically low in terms of quantity and quality consequently affecting both the growth and reproductive performance of the livestock. Mucuna can be used as forage, silage, and hay, and can produce high amounts of biomass depending on rainfall even in soils with low available P (Cook et al., 2005), which makes it an appropriate crop for mixed crop-livestock smallholder farming systems.

From the above maize–mucuna rotations appear to be a promising technology to improve soil fertility, and crop and livestock productivity. However, a clear understanding of the attainable productivity of such systems is lacking, and to what extent these can satisfy both crop (soil improvement) and livestock (feed) needs can be satisfied remains unknown. To quantify biomass production and WP of different cropping systems and their long-term impacts on soil fertility experimentally is extremely cost and time consuming. A preferred approach is to use well-proven crop simulation models, hence a modeling approach was taken in this study. The model used was the Agriculture Production Systems sIMulator (APSIM). APSIM is a modular modeling framework that can be used to simulate complex climate–soil–vegetation management systems (McCown et al., 1996; Keating et al., 2003). It has been tested in Africa to evaluate crop production under a wide range of management systems and conditions. In the Sahel zone, for example, Akponikpe et al. (2010) investigated millet response to N with a view to establish recommendations for N application better adapted to smallholder farmers. Delve et al. (2009) evaluated P response in annual crops in eastern and western Kenya. Ncube et al. (2008) assessed the impact of grain legumes on cereal crops grown in rotation in nutrient-deficient systems in Zimbabwe. Shamudzarira (2003) evaluated the potential of mucuna green manure technologies to improve soil fertility and crop production in southern Africa, while Robertson et al. (2005) evaluated the response of maize to previous mucuna and N application in Malawi.

Published research work on field experiments of maize–mucuna rotations in Zimbabwe is mostly on a short-term basis, and these cropping systems have mainly been tested for crop improvement especially in cereal grain production. Long-term effects of maize–mucuna rotations on soil fertility and attainable production of food and feed have not been tested under smallholder farming systems in the semi-arid areas of Zimbabwe. However the livestock feed issues are not dealt with in this paper. The APSIM model was used in this study to evaluate the long-term effects of maize–mucuna rotations (i) on biomass production, grain yield, and water productivity of maize and mucuna, (ii) on dynamics of soil organic carbon and total nitrogen, and (iii) to investigate the degree of water and nitrogen stress in maize–mucuna rotation systems across seasons.

## 2. Materials and methods

### *2.1. APSIM model description and parameterization*

The predictive performance of APSIM for maize grain and stover yield and mucuna biomass was tested under three fertility treatments namely the control (no fertility amendments), microdose (17 kg N $ha^{-1}$) (Twomlow et al., 2008) and recommended (52 kg N $ha^{-1}$) fertilizer application on two soil types (Masikati, 2011). The field experiments used to evaluate the model were carried out at the International Research Institute in the Semi-Arid Tropics (ICRISAT), Matopos Research Station (20°25′ south and 28°24′ east) during the cropping season 2008–2009. With regards to mucuna, the model was evaluated only for the recommended (RC) treatment, as mucuna did not respond to the different P fertilizer application rates under the microdose (MD) and the recommended (RC) treatments (Masikati, 2011). This could be attributed to soil P levels which were >10 ppm and considered to be optimal for mucuna production (Reuter et al., 1997). The model satisfactorily simulated these management practice differences within experimental error (Fig. 1a and b). The root mean square error (RMSE) for maize grain, maize stover and mucuna biomass across treatments was 404, 599 and 304 kg $ha^{-1}$, respectively.

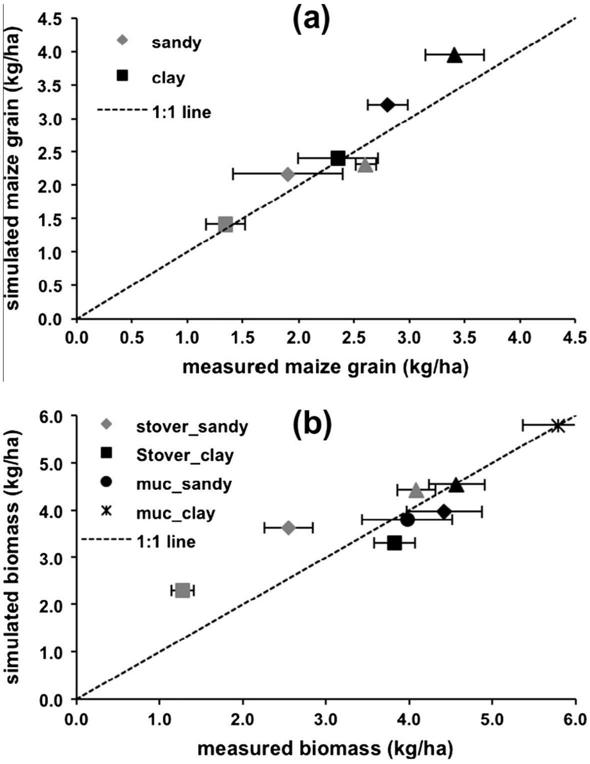

**Fig. 1.** (a and b) Simulated and observed maize grain yield (a) and maize stover and mucuna biomass (b) on clay and sandy soils. Maize grain yield under the FP, MD and RC treatments are shown by the different shapes as square, diamond and triangle, respectively.