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Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity

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ABSTRACT

In Malawi and throughout much of Africa, maize yields have declined over the past several decades due to continuous cultivation, often in monocropping with little or no inputs. As a result, soil degradation has been aggravated by the loss of valuable top soil caused by rainwater runoff due to the absence of effective conservation practices. To combat this trend, Conservation Agriculture (CA) systems were introduced using a pointed stick or hand hoe to plant directly into untilled soil with crop residues as surface mulch. The objective of this study was to compare the effects of different cropping systems (CA and conventional) on soil physical and chemical parameters and long-term maize productivity in target communities of the southern and central regions of Malawi. This study analysed the effects of CA on soil parameters and maize yield over eight cropping seasons. The biophysical variability of the communities was explored through principal component analysis. Results showed that maize yields in CA systems were strongly affected by rainfall infiltration, which was 24–40% greater compared with the conventional ridge and furrow system. In some cases, maize yields in CA plots were double that of conventional tillage plots. The larger water infiltration observed in CA plots relative to conventional tillage indicated that CA systems may increase access to soil water by the crop and offset the negative effects of seasonal dry spells. Yield benefits of CA over conventional tillage systems were greater especially from the 5th season although, in some instances, greater yields on CA were recorded almost immediately. CA can be practiced in diverse environments from sandy to clay soils, nutrient rich to infertile soils and from low to high rainfall areas as long as adequate inputs (fertilizer, herbicides and labour) are available with good extension support to farmers, especially in the initial years.

1. Introduction

Agricultural productivity is important in Malawi because agriculture contributes nearly 35% of the gross domestic product (GDP) while employing more than 80% of the total labour force (Ngwira et al., 2012a). The United Nations Human Development and Poverty Index ranks Malawi 153 out of 169 countries with 74% of the population earning less than $1.25/day and 53% living in severe poverty (UNDP, 2010). Most farmers are small-scale farmers with land holdings ranging from 0.2 ha in the densely populated areas of the south, to 3 ha in the north where the population density is lower (Ellis et al., 2003). Maize (*Zea mays* L.) is the main and preferred staple food crop dominating the farming systems with about 75–85% of land area (Smale et al., 1991). The continuous maize cultivation often leads to a decline in yields due to little or no nutrient inputs, poor land and water management practices, and lack of crop rotations.

Conservation Agriculture systems were first introduced in Malawi by Sassakawa Global 2000 (Ito et al., 2007). Since 2004, there have been several other initiatives to promote CA mostly in the southern and central regions of Malawi in response to the challenges of food insecurity due to low crop productivity. Malawi has low livestock densities which makes the retention of crop residues in CA systems more feasible due to low demand for fodder to feed animals (Ngwira et al., 2012a,b). However, the impact of improved CA management practices on soil biophysical properties has not been properly documented in Malawi. Agronomic and soil research in southern Africa has often focused on the short-term effects of CA, and few examples (i.e. from Zimbabwe) exist of long-term trends on soil quality and crop productivity (Thierfelder and Wall, 2012).

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Often the research results were generated on experimental stations in controlled environments, which limits their applicability to the wider farming context, especially among poor smallholder farmers (Baudron et al., 2012). There is an urgent need to document existing data on CA, generated in the last decade to increase knowledge about this promising cropping system.

Conservation Agriculture (CA) systems are being promoted as productive and sustainable crop management systems in southern Africa (Thierfelder and Wall, 2009) in light of continuous soil degradation (Sanginga and Woomer, 2009), and the need to adapt to a changing climate (Lobell et al., 2008). At the same time, some authors rightfully argue that the promotion of CA systems without sufficient research evidence on plot and farm-level benefits could lead to poor use of donor funding and rejection of the technology by small-scale farmers in southern Africa (Bolliger, 2007; Giller et al., 2009). The promotion of CA as a common, fixed, one-size-fits-all package has also been criticized by various authors because it neglects the need to refine and adapt CA to local circumstances (Wall, 2007; Erenstein et al., 2012; Tittonell et al., 2012). Adaptation of CA principles at the farm level is critical for the long-term success and adoption of CA among farmers in southern Africa, or indeed any area of the world.

In southern Africa, emergency and relief organizations have targeted CA as a system that alleviates poverty for resource-constrained smallholder farmers. The expected full benefits of the system when adequate resources (fertilizers, improved seeds, pesticides) are available are largely unknown (Mashingaidze et al., 2006; Mazvimavi et al., 2008). Despite the abundance of literature on CA from across the world (Bolliger et al., 2006; Hobbs, 2007; Kassam et al., 2009) there is relatively little documented evidence of CA benefits from southern Africa. A detailed research agenda was therefore proposed by Giller et al. (2011) to close these important knowledge gaps.

According to the internationally accepted definition, CA is a cropping system based on three principles: (a) minimum or no soil disturbance by no-tillage seeding; (b) retention of adequate amounts of crop residues or live mulch on the soil surface; and (c) crop rotations with different plant species (Hobbs, 2007; Kassam et al., 2009). Available data on CA systems confirm that a number of short and long-term benefits can be expected when farmers shift from conventional tillage systems to CA (Wall, 2007). Results from the region and around the world show that CA has immediate biophysical and socio-economic effects such as increased water infiltration into the soil due to the protection of surface structure by mulch (Thierfelder and Wall, 2009), reduced water run-off and loss of top soil by maximizing the capture of rainfall and resulting increased infiltration from the ponding effect of the residues (Roth et al., 1988), reduced evaporation of soil moisture as the crop residues protect the surface from solar radiation (Lal, 1974), improved crop water balance (Farooq et al., 2011), less frequent and intense moisture stress because of the increased infiltration and reduced evaporation (Mupangwa et al., 2008; Thierfelder and Wall, 2010a), reduced traction and labour requirements for land preparation and for weeding if herbicides are used, hence saving costs of manual labour, animal draft and fuel, depending on the farming system used (Sorrenson et al., 1998; Ngwira et al., 2012a).

Long-term effects of CA such as increased soil organic matter resulting in better soil structure, higher cation exchange capacity and nutrient availability, and greater water-holding capacity have also been reported (Sidiras et al., 1983; Derpsch et al., 1986; Sisti et al., 2004; Bescansa et al., 2006; Thierfelder and Wall, 2010b). However, the results are variable and depend largely on management intensity, application of all principles of CA and the bio-physical environment (Govaerts et al., 2009; Thierfelder and Wall, 2012). It is often hypothesized that improvements in soil quality will eventually lead to higher and more stable yields, reduced production costs and increased biological activity in the soil and aerial environment, which could also reduce pest and disease pressure. However there are only few examples of published literature from southern Africa available to support this.

The objective of this study was to compare the effects of different cropping systems (CA and conventional) on soil physical and chemical parameters and long-term maize productivity in target communities of the southern and central regions of Malawi. In addition, the benefits of CA were analysed across different agro-ecologies as defined by annual rainfall, soil type and altitude.

2. Materials and methods

2.1. Description of target communities

The study was carried out between 2004 and 2012 in nine target communities of central and southern Malawi (Fig. 1). Malawi is a sub-tropical country with a sub-humid climate situated between latitude 9° and 18°S and 33° and 36° in South Eastern Africa and is divided into three main regions: north, central and south regions. The communities were selected in five districts of Machinga, Balaka, Dowa, Salima and Nkhotakota (Table 1). The first experiments were conducted at Malula in Balaka district, where the study started in 2004. In 2005, Chipeni in Dowa district, Zidyana and Mwansambo in Nkhotakota district were initiated. In 2006, Lemu and Herbert in Balaka district and Matandika in Machinga district followed. The last selected communities were Linga in Nkhotakota in 2007 and Chinguluwe in Salima in 2008. The communities are characterized by a distinct rainfall gradient. Most of the communities around Balaka are in low rainfall areas (600–800 mm) and are prone to drought. The communities of Dowa and Salima are intermediate (800–1000 mm) and the communities in Nkhotakota have higher rainfall (1000–1300 mm). Matandika in Machinga district is an exception as it is influenced by the Zomba plateau with annual rainfall averaging between 800 and 1000 mm (Table 1). Soil textures range from loamy sands in Balaka to sandy clay loams in Nkhotakota. The study areas are all deforested due to high population pressures for growing crops and collecting wood for fuel and building material. Maize is the main food crop grown in all areas, often in a monoculture but sometimes intercropped with pigeonpea (*Cajanus cajan* L. Millsp) and cowpea (*Vigna unguiculata* L. Walp). Groundnuts (*Arachis hypogaea* L.) and cassava (*Manihot esculenta* Crantz) are also important food and cash crops. Other cash crops are mostly tobacco (*Nicotiana tabacum* L.), cotton (*Gossypium hirsutum* L.) and some horticultural crops.

2.2. Experimental design

Six experiments were established in each target community. Each experiment had three treatments at one farm and was treated as a replicate, plot sizes were 0.1 ha per treatment. Similar trials have previously been described by Ngwira et al. (2012a). The treatments were as follows:

- Conventional ridge and furrow system with maize (CPM): Ridges were formed each year approximately 75 cm apart. Residues from the previous maize crop were placed in the furrow before forming the ridges. The ridge is then built on top of the buried residues. The in-row spacing was 25 cm to achieve a plant population of 53,333 plants ha^{-1} as the target population. Planting was done with a hand hoe in CPM on the ridges prepared in September and October. Weed control was achieved by traditional methods with the hand hoe through re-ridging and banking, which are all meant to rebuild the ridges and achieve a weed free seedbed. Weeding in this treatment was limited to two and sometimes