Field Crops Research 155 (2014) 10–13

Contents lists available at ScienceDirect

Field Crops Research

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

A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity

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ARTICLE INFO

Article history:
Received 28 September 2013
Received in revised form 6 October 2013
Accepted 6 October 2013

Keywords:
Mulch
Integrated Soil Fertility Management
Smallholder farmers
Organic resources

ABSTRACT

Intensification of agricultural systems in sub-Saharan Africa (SSA) is considered a pre-condition for alleviation of rural poverty. Conservation Agriculture (CA) has been promoted to achieve this goal, based on three principles: minimum tillage, soil surface cover, and diversified crop rotations. CA originated in regions where fertilizer is commonly used and crop productivity is high, ensuring an abundance of crop residues. By contrast, crop yields are generally low in SSA and organic residues in short supply and farmers face competing demands for their use. Since minimal tillage without mulch commonly results in depressed yields, the use of fertilizer to enhance crop productivity and organic residue availability is essential for smallholder farmers to engage in CA. This is especially true since alternative ways to increase organic matter availability have largely failed. A case study from Kenya clearly demonstrates how fertilizer increases maize stover productivity above thresholds for minimal initial soil cover required for initiating CA (about 3 tonne ha^{-1}). We conclude that strategies for using CA in SSA must integrate a fourth principle – the appropriate use of fertilizer – to increase the likelihood of benefits for smallholder farmers.

1. Introduction

In recent years, Conservation Agriculture (CA) has been promoted to intensify smallholder farming system sustainably in sub-Saharan Africa (SSA) (Benites and Ashburner, 2003; FAO, 2011). Conservation Agriculture is commonly defined around a set of three principles: minimum tillage, soil surface cover, and diversified crop rotations. One of the main justifications for promoting CA in Africa is its widespread use in large-scale farming in various parts of the world (Bolliger et al., 2006; Kassam et al., 2009), with some adoption by smallholders, e.g., in southern Brazil and Paraguay (Evers and Agostini, 2001). This has been partly driven by the presence of an enabling environment, including the availability of herbicides. It is important to note, however, that definitions of 'smallholder farmers' are not consistent. In southern Brazil, a smallholder is classified as farming less than 50 ha, whereas in SSA, smallholder farmers commonly have access to less than 2 ha. While some of the initially hypothesized benefits of CA including soil carbon sequestration and increased crop yields have not been unequivocally confirmed (Govaerts et al., 2009; Luo et al., 2010), CA often results in more stable and economically favourable yields, usually after a number of years after conversion from conventional agriculture (Knowler and Bradshaw, 2007; Rusinamhodzi et al., 2011).

Uptake of CA by smallholders in SSA remains limited (Kassam et al., 2009; Andersson and D'Souza, 2013) and a number of important constraints to widespread adoption have been highlighted. The lack of organic resources to provide sufficient surface mulch consistently ranks amongst the top constraints (Erenstein, 2002; Giller et al., 2009), especially in areas with high livestock feed requirements (Valbuena et al., 2012). Minimal tillage without surface mulch usually results in depressed yields (Verhulst et al., 2011; Baudron et al., 2012; Thierfelder et al., 2013), partly because mulch provides the necessary conditions for reduced run-off and soil moisture conservation, notably in drier climates (Mupangwa et al., 2012). Mulch also ensures that the physical conditions of

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0378-4290/$ – see front matter
http://dx.doi.org/10.1016/j.fcr.2013.10.002

the topsoil are conducive for seed germination and initial crop growth.

In this paper we argue that a fourth principle – the appropriate use of fertilizer – is required to define CA to enhance both crop productivity and produce sufficient crop residues to ensure soil cover under smallholder conditions in SSA. This paper is not meant to advocate CA but argues that without acknowledging this fourth principle the chance that CA will achieve success, especially with smallholder farmers, is limited. Fertilizer application is proposed as a separate principle for CA in contrast to other agronomic practices, including planting time, spacing, and weeding regime, because fertilizer is essential for CA to work, whilst the sub-optimal implementation of other crop management practices do not lead to the failure of CA as such. Moreover, given the reframing of CA in SSA from a resource-saving to a productivity-enhancing paradigm (www.fao.org, Andersson and D'Souza, 2013), and recognizing that fertilizer use is essential to raise crop productivity on most African soils (e.g., Mwangi, 1997; Abuja Fertilizer Summit, 2006), the proposed fourth principle is fully aligned to this reframing of CA. Although this principle also applies to other continents, we chose to focus this paper on SSA since this is the continent where CA is commonly promoted in areas with little or no availability or use of fertilizer.

2. The origin of CA and its three principles

The CA revolution in the tropics started in the 1970s with large-scale farmers in Brazil (Landers, 1999), and spread to other countries in Latin America and certain parts of South Asia (e.g., the Indo-Gangetic basin; Gupta and Sayre, 2007). Minimum or no-tillage with mulching was advocated to reduce the impact of rain on exposed soil and consequent soil erosion losses (Landers, 1999; Roose and Barthes, 2001). An important benefit of minimum or no-tillage was the energy saved by eliminating several tillage operations. Fertilizer use was already a widespread practice in these systems where high crop yields were common. Fertilizer combined with reduced tillage results in increased soil surface biomass to provide sufficient soil cover, especially in areas with segregation of crop and livestock production, as is prevalent on large-scale farms in the areas mentioned above. Agro-chemicals, including fertilizer and herbicides, are readily available and widely used in all regions in which CA has been adopted. Diversified crop rotations are an important element of good agricultural practice, not restricted to CA but also embraced by other approaches to sustainable intensification, including Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010) and agroforestry (e.g., Jama et al., 1998). Crop rotations allow the inclusion of nitrogen-fixing legumes and break pest and disease cycles of crops that are too frequently planted in the same field. Yet rotations do not always results in improved pest control, as some pests can be stimulated, for instance when large amounts of readily decomposable mulch are present (Chikowo et al., 2004).

3. Smallholder farming and CA

Smallholder farming conditions in SSA differ from large-scale farming situations in many aspects relevant to implementation of CA. First of all, smallholder crop yields are often poor due to the limited use of agro-inputs and labour (e.g., Tittonell and Giller, 2013), with little crop residue produced as a consequence. Secondly, in many smallholder farming systems in SSA, there are competing demands on available crop residues, especially for livestock feed (Giller et al., 2009; Valbuena et al., 2012). Thirdly, where population densities leads to fallow land being virtually absent, management-induced soil fertility gradients are created due to a concentration of scarcely available organic resources, either direct or processed, e.g., as manure or compost, in small areas, usually around the homestead (Harris, 2002; Tittonell et al., 2005). This further degrades more remote plots through nutrient mining, a lack of organic matter recycling and erosion due to lack of soil cover. The consequence is that at the planting of a subsequent crop, the cover of crop residues falls below the 30% required to reduce inter-rill soil erosion substantially (Allmaras and Dowdy, 1985), even if all of the crop residues are recycled. Since the relationship between erosion reduction and mulch cover is exponential, more cover results in strong reductions of erosion (Erenstein, 2002). Mulch also reduces weed growth although substantially greater soil cover is required to suppress weeds (Naudin et al., 2011). In Central Kenya, Guto et al. (2011) showed that with stover yields below 3 t ha^{-1}, or equivalent grain yields below 2.5 t ha^{-1} (assuming a harvest index of 0.45), surface cover is less than 30% at the onset of the season (Fig. 1a). Average maize grain yields in Kenya for the period 2006–2011 were 1.6 ha^{-1} (www.fao.org) with an equivalent stover yield of 1.9 t ha^{-1}; well below the above threshold. However, maize grain yields can easily reach 4 t ha^{-1} (Vanlauwe et al., 2006) in the fertilized homestead plots, which are usually less than 10% of the farm land (Tittonell et al., 2010). Average maize grain yields in SSA varied between 1.0 and 1.8 t ha^{-1} for the period 2006–2011, except for the southern African region (3.8 t ha^{-1}) (www.fao.org). Thus crop productivity in African smallholder systems is commonly below the threshold required to provide sufficient mulch to implement CA successfully.

4. The quest for organic resources

Before the widespread promotion of CA, many attempts were made to enhance the availability of organic resources in smallholder farms. These were mainly driven by the search for low-input agricultural practices and the widespread belief that fertilizers were beyond the reach of African smallholder farmers. Examples include alley cropping systems (e.g., Kang et al., 1981), integration of herbaceous legumes (e.g., Carsky et al., 2001), improved legume tree fallows and biomass transfer systems (e.g., Sanchez et al., 1997). Over time, it was realized that the interest of smallholder farmers in the above technologies was disappointing, commonly due to poor crop response (Hauser et al., 2006), management requirements beyond farmers' labour availability (Dvorak, 1996) and/or the lack of immediate benefits to farmers (e.g., Sidibé, 2005). Further, fertilization with phosphorus and other nutrients is generally required to stimulate productive growth of nitrogen fixing legumes to provide the mulch needed (Giller and Cadisch, 1995). With the recent upsurge of interest in CA, some of these options are again being considered to provide the organic resources required to engage in CA. Some approaches place CA amongst technologies that can intensify agricultural systems with limited or no use of fertilizer (e.g., Garrity et al., 2010). In this context, The Montpellier Panel (2013) classified conservation farming under the heading 'ecological intensification', a paradigm that promotes intensification with reduced use of fertilizer whilst capitalizing on ecological processes (De Schutter, 2010). Obviously, earlier constraints to adoption of these technologies remain when implemented in the context of CA. Moreover, CA is not a 'green technology' that does not require the use of external inputs, since fertilizer and herbicides are intensively used in areas where CA has taken off, and are major factors in its success. Gowing and Palmer (2008) concluded that 'CA does not overcome constraints on low-external-input systems in sub-Saharan Africa'.

Since the Abuja Fertilizer Summit in 2006, fertilizer use has regained emphasis in the context of agricultural intensification in Africa, with a specific focus on maximizing the use efficiency