CHAPTER 2

LITERATURE REVIEW

2.1 Conventional smallholder agriculture in Zimbabwe

Zimbabwe's population is estimated at 12.75 million people in 2011, with roughly 61% living in rural areas and 56% of the population in the agriculture workforce (FAOSTAT, 2012). The country is divided into six natural or agroecological regions, based on land-use practices and climate/rainfall patterns (Raes et al., 2004) (Figure 5, Table 1). In 1999, there were an estimated 1.57 million farms of which more than 99% were classified as small-scale farms, defined as farms occuring on communal land and in resettlement areas with arable land averaging between 3-5 ha/farm (FAO, 2006). Approximately 70% of the communal land and resettlement area exist in the driest regions—Natural Regions IV and V. Most large-scale farms occur in Natural Regions I, II, and III, where rainfall is higher and more reliable. Regions IV and V have the lowest rainfall (<650 mm), are subject to drought and prolonged dry periods during the rainy season, and often have infertile soils (FAO, 2006).

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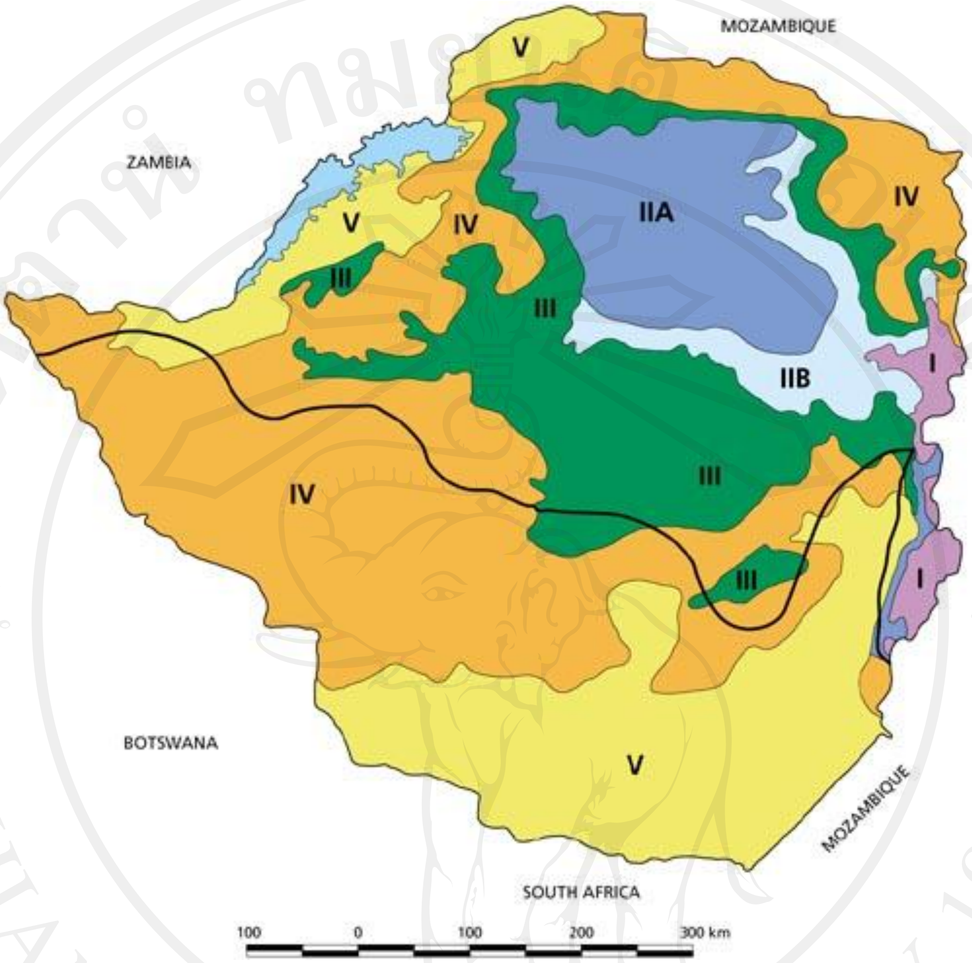

Figure 5: Natural Regions of Zimbabwe.

[a] Source: FAO (2006)

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Table 1: Description of Zimbabwe's Natural Regions

Region	**Area km^2 (% of land area)**	**Rainfall (mm/yr)**	**Farming System**	**Rainfall pattern**
I	7,000 (2.0)	>1,000	Specialized, diversified, commercial	Rain distributed all months (high elevation)
IIA, IIB	58,600 (15.0)	750-1000	Intensive, field cropping and livestock	Summer rainfall, Some drought
III	72,900 (18.5)	650-800	Semi-intensive, livestock and cropping	Heavy showers, seasonal drought
IV	147,800 (38.0)	450-650	Semi-extensive, smallholder farming and livestock;	Erratic distribution; severe dry periods
V	104,400 (26.5)	<450	Extensive, livestock and subsistence farming	Very erratic rainfall; frequent severe droughts

[a] Adapted from FAO (2006), Phillips et al. (1998); and Gambiza & Nyama (2000)

[b] Based on Vincent and Thomas (1960), *An agricultural survey of southern Rhodesia: Part I. Agro-ecological survey* and *Moyo (2000), Ed: Zimbabwe environmental dilemma: balancing resource inequities*, as cited in FAO (2006); Phillips et al. (1998); and Gambiza & Nyama (2000)

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In the 2010/2011 season, major field crops by area and yield, respectively, were maize (>2 million ha, 0.69 t/ha), groundnut (426,806 ha, 0.54 t/ha), cotton (379,689 ha, 0.58 t/ha) sorghum (304,693 ha, 0.31 t/ha), and pear millet (164,895 ha, 0.27 t/ha) (Zimbabwe Minister of Agriculture, 2011). Zimbabwe's communal areas currently produces the largest share of the nation's total maize production (compared to small, medium, and large-scale commercial farms)— 40% in 2009/10 and 43% for 2010/2011 (Zimbabwe Minister of Agriculture, 2011). According to FAS (2012), the average maize yield in Zimbabwe for 2012 was 0.92 t/ha with a 10 year average of 0.65 t/ha.

2.2 Tillage impacts in Zimbabwe

Land preparation in Zimbabwe among smallholder farmers is done primarily with an animal drawn single moughboard plough (Munodawafa, 2007). Livestock are usually grazed on residues during the dry season resulting in minimal soil cover. Soil inversion from ploughing results in further clean, or bare ground, cultivation typical in traditional smallholder systems. While surface infiltration is initially enhanced, the ploughing action accelerates organic matter mineralization, decreases quality of soil structure, and exposes the loose soil to sheet erosion (Braithwaite, 1976 as cited in Munodawafa, 2007).

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Figure 6: Traditional tillage with single moulboard plough.

Figure 7: Typical ploughed field, Nkyai District, Zimbabwe. End of dry season, 2011 with bare ground, high surface temperatures, surface crusting, and evidence of erosion.

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Most of the tillage research until the 1980s in southern Africa centered on large-scale farming methods (Willcocks & Twomlow, 1993). However, growing concern over land degradation in the smallholder sector, especially high rates of soil erosion, resulted in increasing tillage research for smallholders (Vogel, 1992; Willcocks & Twomlow, 1993). In Zimbabwe, a series of long-term tillage studies were initiated in 1988 at two sites evaluating conventional tillage (CT) with several animal drawn conservation tillage methods and hand-hoeing (Vogel, 1992). The animal drawn minimum till methods included: 1) clean-ripping—use of a ripper to open up lines for planting; 2) mulch-ripping—same as clean-ripping except crop residues remain in the field; and 3) tied-ridges— a series of semi-permanent ridges where maize is planted and cross-ties exist in furrows acting as micro-dams to trap water and sediments (Nyagumbo, 1999).

In the same trial, Chivenge et al. (2007) investigated the tillage and residue management effects on SOC after 9 seasons (1988/89-1997/98). CT had the lowest SOC in both clay and sandy soil when compared to three other treatments—clean-ripping, mulch-ripping, and tied-ridges. Tillage effects were more significant on clay soil suggesting the reduced tillage practices are best for carbon sequestration on finer textured soils. In sandy soils, the authors observed that tillage practices alone had no significant effect on improving SOC, except for mulch-ripping—the only treatment with residue retention. The authors concluded that SOC improvements on sandy soil is better achieved by carbon-based inputs (e.g. residue retention, manure) than tillage treatments alone (Chivenge et al., 2007).

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Munodawafa and Zhou (2008) in the same trial found water run-off and soil loss from CT to be significantly higher than mulch-ripping and tied ridges during a three year study period (1993-1996) at Makoholi Research Station, Zimbabwe—a semi-arid, sandy soil site in Natural Region IV. The percent of total annual precipitation that occurred as run-off from CT averaged 19% (104 mm/yr) compared to 7% (40 mm/yr) and 6% (34 mm/yr) for mulch-ripping and tied-ridges, respectively. Average CT soil loss was 34 t/ha/yr compared to 2 t/ha/yr in mulch-ripping and tied-ridges. Yield differences were not significant, but trended higher in mulch-ripping and tied-ridges than in CT. Yields varied least in mulch-ripping (2.2-3.9 t/ha) and tied-ridges (1.1 to 3.7 t/ha) compared to much higher yield variation in CT (0.9 to 4.6 t/ha). CT recorded the lowest yield in the study which occurred during the driest season (Munodawafa & Zhou, 2008).

Munodawafa (2007) further investigated nutrient loss of N, P, and K in both water and sediment run-off over three years on sandy soils under the same three tillage treatments. N and K losses were signficant in CT, averaging 15.8 and 34.5 kg/ha/yr, respectively, compared to losses in mulch-ripping (averaging 2.3 and 0.6 kg/ha/yr) and tied-ridges (2.7 and 4.3 kg/ha/yr). Overall P losses were low in all three treatments (under 1 kg/ha/yr), but significantly higher in CT than in all other treatments. The vast majority of nutrient transport came through sediment run-off versus negligible amounts in water run-off. In a fourth non-cropping treatment—bare fallow—land was ploughed and maintained clean of weeds through the rainy season. Bare fallow treatment sediment loss was nearly triple the loss of CT, and N and K losses were nearly double CT. Munodawafa (2007) attributes the low soil/nutrient loss

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under mulch-ripping and tied-ridges due to increased infiltration from enhanced soil quality under practices that minimumally disturb the soil. The mulch-ripping had the further benefits of soil coverage from crop residues.

2.3 No tillage and CF

Though differences exist across soil types, climates, and seasons, Zimbabwean tillage studies demonstrate that systems with least soil disturbance, as in mulch-ripping and tied-ridges, are generally superior to CT for conserving water, soil and fertility resources. CT as practiced by smallholders remains a long-term unsustainable system (Nyagumbo, 1999). However, despite decades of promotion in the smallholder sector, there has been a low uptake of minimum tillage systems in the smallholder sector (Mupangwa et al., 2006). Many researchers have concluded a single technique does not address the many challenges African smallholder farmers face. These constrainsts include already low mechanization options, lack of implements, high weed pressure in absence of ploughing, limited access to appropriate fertlity inputs, use of crop residues for livestock feed, labor availability, etc. (Twomlow et al. (2006) in *Dryland farming in southern Africa* as cited in Twomlow et al. 2008b). Against this backdrop, one system that is popular among a critical mass of farmers, researchers, and development agencies and has seen spontaneous adoption in both the Zimbabwean and Zambian smallholder sector is CF, a hoe-based farming system involving pemanent planting stations. CF combines the proven soil and water conserving practices of minimum soil disturbance and residue retention with high agronomic standards and practices to achieve resource-use efficiency, high yields, and profitability (Twomlow et al., 2008b; Haggblade and Tembo, 2003b).

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2.4 CF Origin

CF development and early promotion is attributed to a former commercial Zimbabwean farmer, Brian Oldreive, who managed the Hinton Estate's farming enterprise in Mutepatepa during the early 1980s to mid-90s (Twomlow et al., 2008b). Oldreive initially managed the estate conventionally with deep ploughing and harrowing but the result was declining yields and profits (Oldreive, n.d.). Compelled to consider alternatives, Brian Oldreive experimented with small plots under no-tillage using planting holes made with hoes into the previous season's crop residues and implementing very high management standards. His early successes with this approach eventually led to the conversion of Hinton Estate's accumulated 3500 hectares to mechanized no-till farming (Oldreive, n.d.). Believing this farming approach had significance for the vast majority of hoe-based farmers through sub-Sahara Africa, Oldreive continued to experiment with the hoe-based technology.

2.5 CF Distribution among smallholders

The first practical and wide scale extension of this technology actually occurred in Zambia where Oldreive was brought in as a consultant by the Zambia National Farmers Union (ZNFU) in 1995 (Haggblade and Tembo, 2003b). Already in place was an existing positive momentum among commercial farmers toward no-tillage due to profitability increases from dramatic reductions in fuel usage (120 liters to 30 liters/ha) and the resulting improved soil conditions under minimum tillage. Oldreive's contribution, however, was in bringing knowledge of the hoe-based method of fixed planting stations for improving smallholder production. CF research trials were implemented at the Golden Valley Agricultural Research Trust (GART),

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followed by on farm trials in successive years. Through widespread promotion, incentives, and spontaneous adoption, by the 2002/3 season there was an estimated 75,000 Zambian farmers practicing CF, mainly among maize and cotton smallholders. Maize yields were double that of conventional ploughing, partly attributable to the higher inputs of fertilizer and hybrid seed. The 60% increase in cotton under CF, however, came with the same input package that conventional cotton farmers used provided by the Dunavant Cotton Company (Haggblade and Tembo, 2003b).

In Zimbabwe, early promotion of CF began through the organization Farming God's Way (FGW) led by Brian Oldreive which today is known as Foundations for Farming (FfF). An early extension group under FGW called Operation Joseph provided the first wide scale extension efforts within Zimbabwe beginning in 2000 (Twomlow et al., 2008b). In 2003, the growing interest in CF as a solution to extremely low yields of Zimbabwean smallholders resulted in the formation of The Zimbabwean Conservation Agriculture Task Force (ZCATF) spearheaded by FAO. This group comprised multiple NGOs and research institutions such as CIMMYT and ICRISAT (Twomlow et al., 2008b). The original goal of the ZCATF was to promote CF and provide a comprehensive training and resource package that NGOs could incorporate into traditional relief efforts among vulnerable households. In 2005, the ZCATF agreed upon 8 components to CF: 1) winter weeding; 2) hoe-based planting basins; 3) crop residue retention; 4) manure application; 5) basal fertilizer application; 6) top dress fertilizer application; 7) timely weeding; and 8) crop rotations. CF also became labeled as part of an overall conservation agriculture farming package called PCA, Precision Conservation Agriculture, from ICRISAT scientists. Promoted

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among 50,000 households over four years, maize yield increases from 50-300% were documented. (Twomlow et al., 2008a). Though the majority of current CF farmers appear to be in Zambia and Zimbabwe, CF has been promoted in many African countries through a number of NGOs and research agencies. The no-till hoe-based permanent planting station method of farming is known by many names including CF, CA (Conservation Agriculture), basin farming, basin tillage, "holing out", and precision conservation agriculture (PCA).

2.6 CF Research comparing CF to CT

2.6.1 Agronomic

CF has 4 main agronomic advantages over CT systems:

1. *Early planting.* The off-season hole preparation positively impacts seeding dates, facilitating earlier planting with the first rains—a critical advantage over ploughed fields especially in erratic rainfall areas. CT can result in delayed planting due to waiting period for rain events to create favorable tillage conditions (Langmead, 2004; Woodring & Braul, 2011). According to Lowe (2009), 1.4% yield loss potential occurs each day maize planting is postponed after sufficient rainfall for planting. In a modeling study of over 750 Zambian CF farmers, Langmead (2004) reported 29% of the yield increases associated with CF are attributed to earlier planting dates than are commonly found under conventional smallholder farming methods. Haggblade et al. (2011) reported cotton farmers as the most loyal adopters due to significant advantages of early cotton planting that CF facilitates. IFPRI (International Food Policy Research Institute) together with ZFRP (Zambia Food Security Research Project) conducted a survey of 125 maize and cotton farmers using the permanent planting station technology in the Central and Southern Provinces of

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Zambia. 87% of smallholder farmers interviewed cited higher yields with basin technology over conventional tillage. Farmers indicated earlier planting and improved water harvesting as the two main factors contributing to higher yields (Haggblade and Tembo, 2003a). Successful early planting also results in earlier crop canopy soil cover. Soil coverage by developing maize canopy and previous season residues is critical to reducing erosion which is usually highest under early season downpours when crop coverage is low (Vogel, 1992).

2. *Uniform planting density*. Farmers using CF more easily maintain uniform maize populations as station spacing and seeding rates are based upon ideal plant densities for specific rainfall regions (Haggblade and Tembo, 2003b). For example, in low rainfall areas (<650 mm), the station spacing recommendation is 75 X 75 cm or 90 X 60 cm, resulting in approximately 18,000 stations or 36,000 maize plants. Thus, the fixed stations help farmers achieve uniform stands of maize in successive years, optimizing crop synergies while minimizing plant competition and weed pressure. Such precision in layout also helps farmers accurately estimate seed and input purchases. Haggblade and Tembo (2003b) determined that 25% of farmers overestimate field sizes while 20% underestimate field size, both situations leading to mismatched inputs of seed and fertilizer.

3. *Precise input application*. The CF permanent planting station technology facilitates precise application and efficient use of fertility inputs in contrast to broadcasted manure applications in ploughed fields (Haggblade and Tembo, 2003b, Mazvimavi et al., 2008). For example, one level beer bottle cap of compound D is prescribed for a basal fertilizer application, equivalent to 80 kg/ha, and placed directly below where maize seeding occurs (Twomlow et al., 2008a).

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4. *Consistent, high yields.* CF production is higher, more consistent, and less vulnerable to erratic rainfall (ZCATF, 2008). Yield gains between 10 and 100% were documented in a 3 year study of CF farmers with consistent gains across all four natural rainfall regions (Mazvimavi et al., 2008). Haggblade et al. (2011) suggested that 25% of CF yield gains came from increased input use (e.g. basal fertilizer, hybrid seed), 25% due to early planting, and approximately 50% from other positive contributions of CF components such as increased field conditions under no-till, mulching, and increased station fertility and water harvesting. Due to higher yields over a given area, the total field area under cultivation can be reduced or partitioned to other farming activities. The yield effect of CF is especially pronounced in low rainfall regions. During drought conditions in 2006/07 in low Rainfall Regions IV and V, CF fields yielded 5 times higher than conventionally ploughed fields (Mazvimavi et al., 2008).

2.6.2 Ecological

CF's effect on soil/water dynamics is most notable with improved pH in planting stations and increased infiltration over CT:

1. *Soil quality.* Belder et al. (2007) investigated soil chemical and physical effects in a timeline study involving 37 households practicing CF for 1-3 years in Zimbabwe. The most notable changes occurred in physical parameters where infiltration rate was higher in CF stations than in conventional fields and bulk density was lower in the upper 15 cm of stations compared to ploughed fields. No significant differences were observed in N, P, and SOC between inside and outside of CF stations and ploughed fields, except for pH which was significantly higher in basins than

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ploughed fields. In the same study, maize yield was also investigated and CF yields were double of conventionally ploughed fields across high and low rainfall regions.

2. *Water dynamics.* A single year water-harvesting study of four tillage methods— CF, ripping, single and double conventional ploughing— demonstrated CF basins to have the highest infiltration of all tillage practices with conventional ploughing having the greatest runoff (Mupangwa et al., 2008).

2.6.3 Socioeconomic effects

Moreover, CF has higher profitability but higher labor inputs than CT. Mixed adoption rates are common.

1. *Profitability*. According to Mazvimavi et al. (2008), a study of farmers in all rainfall regions of Zimbabwe (high, medium, and low), farmers' gross margins were greater in CF fields than farmer practice (CT) with and without fertilizer—the highest margins being achieved by farmers practicing CF two years or more. The greatest gross margin recorded between CF and CT occurred in lowest rainfall regions (approximately ten times higher for CF farmers than CT farmers using fertilizer). An additional savings comes through the elimination of ploughing. No ploughing services are needed for hiring, or maintenance of draught animals and ploughing equipment throughout the year. For households lacking access to draught animals or where cost is prohibitive, CF offers vulnerable households a non-ploughing option.

2. *Labor*. There is different evidence about the amount of labor associated with preparing a CF field. Based on farmer interviews with cotton farmers, Haggblade and Tembo (2003) determined CF farmers averaged 66 person days/ha for field preparation; conventional hoe farmers 59 days/ha; and conventional ploughing 7

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days/ha. According to a farm budget analysis by Mazvimavi et al. (2008), in Natural Regions IV and V, in year two a total of 122 days/season for CF farmers are needed to 77 days for conventional. Some of the major labor differences are accounted for by the 21 days/ha for digging stations versus 15 days required for winter and spring ploughing, and the additional 13 days for mulch placement and 13 days for winter weeding practiced by CF farmers. Under these conditions, the estimated return for labor was calculated at $5.26 USD/day for CF fields to $1.50 USD/day for CT (Mazvimavi et al., 2008). According to Edwards (2011, personal communication, October 7, 2011), approximately 120 hrs are required to establish a one hectare field at 75 cm X 75 cm (equivalent to 15 days at 8 hrs/day). Under CF, weeding demand is reported to increase (Mazvimavi et al., 2008). Haggblade and Tembo (2003a) reported that weeding CF cotton fields at 80 person-days and in ploughed fields at 45 person days with similar results in maize cultivation. While there is clear evidence that the labor input in establishing CF fields is significant, Haggblade and Tembo (2003a) found labor decreases consistently over time and that by year five labor input is approximately half of year one (70 person-days/ha for first year to dig stations).

3. *Farmer adoption.* NGOs have largely been the promoters of CF sometimes providing free inputs with the hope farmers will continue CF beyond free or subsidized inputs. Because of the various approaches by different agencies and NGOs involved, it is difficult to quantify the impact from outside support and reliably estimate smallholder adoption. In the three year CF study by Mazvimavi et al. (2008), of the 232 households interviewed, between 73 and 95% received some kind of support through NGOs. Haggblade and Tembo (2003b) explained the early surge in CF adoption in Zambia to be highly influenced by input packages made available

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from donor agencies to 60,000 farmers in the 2001/02 season.

Partial adoption of the CF package is also common. Of the ZCATF's 8 CF components, farmers tend to not adopt all or drop some components over time. Mazvimavi et al. (2011) conducted a study to examine adoption trends among CF farmers in 12 districts of Zibmabwe over a five year period. The use of inorganic fertilizers both as basal and topdressing decreased respectively from 71 and 94% in 2004/05 to 38 and 70% in 2008/09. In the final season, crop rotation, the application of inorganic basal fertilizer, and application of mulch (crop residue retention) were the least practiced of the 8 components (Mazvimavi et al., 2011). Mulch accumulation, at least to a minimum 30% recommended surface coverage, is a significant challenge for farmers, especially in low rainfall regions (Twomlow et al., 2008a). This is in large part due to traditional communal grazing patterns where there is increased competition for feed resources combined with already lower biomass yields among smallholders. For this reason, some CF advocates place less priority on mulch soil cover.

2.7 Research challenges

The promotion of conservation based farming systems, including CF and other minimum tillage, mulch-based systems have come under recent criticism questioning their viability and appropriateness for smallholders (Giller et al., 2009). There remains a need to evaluate CF outside of reasearch stations and farmer managed research plots to provide real-life assessments of CF under smallholder conditions (Baudron et al., 2012). Longer timeline studies are needed that emphasize CF effects on specific soil types. The infiltration study by Mupangwa et al. (2008) covered only

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one season. The only other published timeline study focuses on 1-3 yr. old CF fields and involved fields on varying soil types (see works of Belder et al., 2007). Furthermore, existing research has largely focused on yield, labor, profitability, and adoption rates analyses among smallholders (see works of Mazvimavi et al., 2008 and Haggblade et al., 2011). There is relatively little research in terms of CF's impact on soil quality and rate of change—which is the primary focus of this study, with modest inclusion of yield data and farmer input from interviews. This research is especially important in light of recent criticism challenging the efficacy of smallholder conservation based farming systems to improve soil conditions and at least sustain profitability.

2.8 Hypotheses

1. Soil fertility and physical parameters are improved in CF fields versus conventionally ploughed fields and best in those fields with the longest time period under CF management due to no tillage, crop residue retention, and concentrated station improvements.
2. Within CF fields, station soil fertility and physical parameters are higher than soil analyzed outside the stations in CF fields due to continued fertility inputs applied by farmers in the same place each year.
3. The simplified active carbon analysis will provide meaningful and less expensive assessments for estimating soil quality in CF research.

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2.9 Research Objectives

1. Examine the rate and quality of soil fertility changes under a minimum-till farming system practiced by smallholder farmers in a timeline study.
2. Determine relationships between analyzed soil conditions, farmer management activities, and yield data.
3. Evaluate the effectiveness of an active carbon test for estimating soil fertility.

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