Options for Improving Smallholder Conservation Agriculture in Zambia

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Abstract

This study examined the agronomic practices of smallholder Conservation Agriculture (CA) farmers in Zambia. Questionnaire survey, focus group discussions, key informant interviews, field assessments, desk study and soil analyses were employed to collect data on tillage systems, crop rotations, weed control, soil fertility management, crop residue retention and crop yields. The results showed that weed management, crop residue retention, timely planting and soil fertility management were the most challenging for CA farmers especially those without reliable access to oxen. Crop residue retention conflicted with the socio-cultural practices of the communities and was hardly practised while crop rotation seemed difficult in light of the dominance of maize cultivation and the lack of markets for crop legumes. Possible options for improving smallholder CA systems were greater integration of livestock, correct herbicide application, market provision for crop legumes, farmer training in agri-business and better access to agricultural credit and subsidized inputs. CA promoters must incorporate the farmers' local cultural contexts in order to better address the challenges associated with adopting CA.

Keywords: Conservation agriculture, Agronomic practices, Smallholders, Conventional agriculture, Zambia

1. Introduction

The dominant narrative of soil degradation in Africa identifies the misuse of land by resource-poor farmers as the most important human- induced, proximate causal agent for the widespread soil degradation in Sub-Saharan Africa today (Mortimore & Harris, 2005). The farmers are said to misuse land through the burning of crop residues, nutrient mining and overgrazing (Thierfelder and Wall, 2009) and failing to incorporate appropriate and sufficient soil conservation practices in their farming systems.

Agriculture, as conventionally practised, is assumed to lead to soil organic matter decline, water runoff and soil erosion (Hobbs, 2007). Depletion of soil fertility, along with the concomitant problems of weeds, pests, and diseases, is a major biophysical cause of low per capita food production in Africa (Sanchez, 2002). One option increasingly advocated for re-dressing soil fertility decline and improving crop productivity and household food security is Conservation Agriculture (CA) (CFU, 2006) .

1.1 Conservation Agriculture

Conservation Agriculture (CA) describes a system based on three principles: minimum mechanical soil disturbance; permanent organic soil cover with crop residues or cover crops; and diversified crop rotations (Thierfelder and Wall, 2009; FAO, 2010) . Benefits of CA claimed in literature include significantly improved physical and chemical properties of soil; increased soil biotic diversity; higher soil organic matter content from constant addition of crop residues (Six et al, 2002) ; reduced production costs (Stoorvogel & Smaling, 1998) and increased yield and reduced pest and disease problems (Gowing and Palmer, 2008) . Soils under CA exhibit high water infiltration rates reducing surface runoff and consequently lower soil erosion (Thierfelder and Wall, 2009:2010a). CA also allows reduction of the time and labour expended, particularly at times of peak demand, on such activities as land preparation and planting (FAO, 2010). Disadvantages claimed are the high initial costs of specialized land preparation and planting equipment (Knowler and Bradshaw, 2007) and the completely new dynamics of a CA system, requiring high management skills and a learning process by the farmer. There have been reports of increased weed burden in the early years following adoption (Haggblade and Tembo, 2003a) .

1.1.1 Conservation Agriculture in Zambia

CA as promoted in Zambia involves a package of several key practices: dry-season land preparation using minimum tillage systems; crop residue retention; precise input application as seeds and fertilizers are placed directly into basins or ripped furrows; and nitrogen-fixing crop rotations. For hand hoe farmers, CA revolves around dry-season preparation of a precise grid of permanent basins. These permanent basins are to be 30cm deep and spaced 70cm along the row and the rows 90cm apart (CFU, 2009a). For oxen farmers, CA involves dry-season ripping, normally with the locally developed *Magoye* Ripper (CFU, 2009b) For commercial farmers, mechanized minimum tillage methods with leguminous crop rotations such as soya beans (*Glycine max*), green gram (*Vigna radiata*) and sunhemp (*Crotalaria juncea*) complete the typology of CA technologies (Haggblade and Tembo, 2003b) . Basin digging is said to explicitly cater for smallholder (Note 1) farmers without reliable access to draught power. By reallocating land preparation to the dry season, in advance of the rains, CA redistributes heavy labour as well as animal and mechanized draught requirements out of the peak planting period. This enables farmers to plant at the very beginning of the rainy season. This is advantageous because crops planted early can benefit from the relatively large quantities of nitrogen found in the soil during this period (Haggblade & Tembo, 2003c).

Although data on the overall adoption of CA is fragmentary, available evidence suggests that between 20,000 and 60,000 Zambian farmers practiced some form of hand hoe CA during the 2001/2002 farming season while an additional 4,000 used rippers (Haggblade and Tembo, 2003a). This figure rose to between 125,000 and 175,000 in 2006 (CFU, 2006). Baudron et al. (2005) reported a 10% adoption rate as of 2003 among Zambian smallholders. Adoption is problematic to delineate as some farmers only adopt some of the recommended practices, while those who adopt CA technology do not apply it on all their plots. Adoption rates are time sensitive as they tend to be tied to active promotion of technologies by NGOs and research institutions. Giller et al. (2009) claimed that most farmers revert to their former crop and soil management practices when project support ends and incentives are discontinued.

CA promotion in Zambia has been done by a coalition of stakeholders from the private sector, government and the donor community. Chief among them are CFU under the Zambia National Farmers Union, Institute of Agricultural and Environment Engineering, Golden Valley Agricultural Research Trust (GART), Dunavant, Cooperative League of the USA (CLUSA), Land Management and Conservation Farming (LM&CF), and Ministry of Agriculture and Cooperatives (MACO) (Baudron et al, 2007) . The funding has mainly been provided by donors. Promotion of CA by the various stakeholders seems to differ in agronomy, in the incentives offered to adopters and pedagogically.

The objective of this study was to evaluate CA under Zambian farming conditions by examining its application among smallholder farmers. The rationale was to determine reasons for any deviations from recommended practices and where possible suggest options through which smallholder CA in Zambia could be improved.

2. Materials and Methods

The study was carried out between June 2008 and December 2009. Data were collected through soil sampling, semi-structured household interviews, focus group discussions; field observations and desk study of the literature on CA.

2.1 Study Areas

Fig.1. Locations of the study areas in Zambia.

Three provinces (and six districts) were selected as study areas based on variations in agro-ecology. Two districts, Monze and Sinazongwe, were selected from the Southern Province, three from Eastern Province (Katete, Chipata, Petauke), and one district, Mumbwa, from Central Province (Table 1 and Fig.1). The study areas were located in two of Zambia's three major Agro-Ecological Regions (AER). Zambia's major AERs have been categorized on the basis of average annual rainfall, length of growing season and relief. These are AERs I, II, and III. AER II is further subdivided into IIa and IIb based on differences in soil type. The selection of the study areas for this study was restricted to AERs I and IIb as these are the two AERs where CA is practised. The six districts were then selected as they were known to have had projects on CA promotion for at least five years.

Table 1: Agro-ecological Characteristics of the study areas

The climate of the study areas, typical of the entire country is characterized by three distinct seasons; a hot-wet season (November-March), a cold-dry season (March-August) and a hot-dry season (August-October).

2.2 Soil Sampling

A total of 73 paired soil samples were collected. A pair was made up of one sample from a field under CA and another from a field under conventional agriculture (Note 2). Each sample was a composite of ten sub-samples, each of which was taken from a depth of between 0-20 cm. Soil sampling was restricted to farmers' fields where CA and conventionally farmed plots were adjacent to each other. This minimized the effects of natural soil variability that is inevitable in fields that are at large distances from each other and made it possible to attribute any differences in the soil chemical and physical properties to soil management practices. The sampling frame consisted of the fields of farmers that had practised both types of farming for a minimum of five years. Using these criteria only eleven paired samples were obtained from Eastern Province. Forty two and twenty paired samples were obtained from Southern and Central Provinces respectively. The soil samples were analyzed for soil reaction pH, bulk density, plant available water, exchangeable potassium, total nitrogen, plant available phosphorus and organic carbon. The techniques used for the analysis were Bray P1 for phosphorus (Bray and Kurtz, 1945) , Modified Kjeldahl Method for total nitrogen (Bremner, 1965), Walkley and Black Method for organic carbon (Walkley and Black, 1934) and ammonium acetate buffered at pH 7 for soil reaction pH. Bulk density and plant available water were determined following the methods outlined in Anderson and Ingram (1993).

2.3 Questionnaire Survey and Focus Group Discussions

Questionnaires were administered to 129 farming households that were practicing both CA and conventional agriculture. These comprised of 36 households from Eastern Province, 32 from Central Province and 61 from Southern Province. The households were randomly selected from CA adopter lists provided by field staff of the Conservation Farming Unit (CFU) in each of the three provinces. According to CFU's records from 2007, each of the six districts surveyed in this study had between 3 000 and 12 000 households practicing CA. The households were interviewed on the following agronomic practices: tillage systems, crop rotations, weed control, cover crops, crop residue retention, and manure and inorganic fertilizer usage. Two Focus Group Discussions, consisting of 8 members each, were conducted. Discussions centered on the benefits of CA; problems encountered in the adoption and practice of CA and how these could be overcome. The focus group discussions were conducted with farmers that were practicing both CA and CV that had not been selected for the questionnaire survey. This was mainly a triangulation tool used to determine the representativeness of the answers from the questionnaire surveys and to get in-depth discussions in a group setting on issues that had been discussed at household level during the questionnaire survey.

2.4 Field Assessments

Field assessments were conducted on tillage practices; weed burden, crop residue retention, crops planted, sizes of plots under different tillage systems, and on the timeliness of land preparation. This information was also captured from study visits to research stations, and farmer field days. Observations were also continuously recorded by field assistants employed from within the local communities. They observed and recorded land preparation dates for the four tillage systems by selected households after agreement and on prior arrangement with them.

2.5 Desk Study

The desk study involved review of research results on CA published by GART (Note 3) during the period 2000-2009 (GART, 2000; 2001; 2002; 2003; 2004; 2005; 2007; 2008; 2009). Research results published in the GART Year Books were reviewed. Focus was on tillage systems comparisons, cover crops, crop productivity and weed management on-station experiments. This review was conducted in order to compare the on-station results with the field assessments of actual on-farm work and farmers' responses from the questionnaire survey. Other studies reviewed included Haggblade and Tembo (2003a:2003b:2003c); Langmead (2004) ; Thierfelder and Wall (2009:2010b). Handbooks published by CFU were also studied for the recommended CA practices.

Crop yields reported by GART (2004), Thierfelder and Wall (2009), Langmead (2004) and IFPRI/FSR (2003) are presented in section 3.8. The experimental design by GART (2004) was split-plot with six treatments replicated four times. The main treatments were the tillage systems ploughing, ripping, ridging and basin digging while the sub-treatments were full and half recommended fertilizer rates. The experiments were conducted from Monze and Chisamba research stations. Thierfelder and Wall (2009) conducted the experiments from Monze Farmers Training College (MFTC). The experimental design was a randomized block design with four replications. All crop residues were removed from the CV plots but retained on the CA treatments. Fertilizer was applied at 165kg/ha for basal (N: P_2O:K_2O, 10:20:10) and 200kg/ha for top dressing (46% N).

Langmead (2004) presented results of on-farm trials conducted in Southern, Western, Central, Northern and Copperbelt provinces. Comparisons were made between CA and CV systems involving three year rotations of maize, a legume and cotton. The farmers were provided with similar inputs except that CA farmers received extension advice while CV farmers did not.

2.6 Statistical Analysis

Statistical analyses were carried out using MINITAB 15 (Minitab, 2009). The results of the soil sampling were analyzed using paired T-test as they were paired samples. The questionnaire survey data were analyzed using ANOVA, two - sample T-test and Pearson's correlations at a probability level of $p \leq 0.05$. Descriptive statistics such as means, standard deviations and percentages were also used to analyze results from the questionnaire survey and field assessments.

3. Results and Discussion

The two farming systems, Conservation Agriculture (CA) and Conventional Agriculture (CV) were categorized based on tillage system. CV was either hand hoe (manual) or ploughing (use of ox-drawn mouldboard plough). CA involved digging of basins (manual) and ripping (use of ox-drawn ripper).

3.1 Tillage Systems

It was common to find a combination of CA and CV being practised by one household. Out of the 129 households interviewed, only one household practised CA on all of its cultivated fields. This household had adopted CA 12 years earlier. The head of this household explained that his household had adopted CA after having been approached by a non-governmental organization that was promoting CA in the area. They were trained in CA practices and provided with agricultural inputs. They converted all their fields to CA over time as they become convinced of its benefits.

3.1.1 Area cultivated based on tillage system

The result from the survey show that the farmers have only partly adopted CA. Comparisons between the total area under CA and under CV revealed no significant differences ($t = 0.19$, $p=0.851$). In the Central and Eastern Provinces, farmers have converted 54 and 51 % of their land to CA respectively. In the Southern Province 34 % of the land has been converted to CA. The Southern Province is mainly inhabited by the *Tonga*, a pastoralist tribe with propensity to keep cattle and engage in ox-farming. This may explain the lower uptake of CA technologies in the Province. Ripping is the most widespread CA technology as the land under ripping is more than double the land under basin. The areas allocated to ploughing and ripping were not statistically different ($t=0.372$, $p=0.71$). Farmers already using oxen to plough were more likely to use the same draught animals for ripping when adopting CA.

The survey results showed that 88 % of the farmers were digging basins while only 25 % of the farmers practiced conventional hand hoe farming. Basin digging was practiced by many on a small piece of land probably as a food security strategy. Average area under basins in Central Province was significantly higher than that for Eastern and Southern Provinces. Basin digging is a labour-intensive activity. The drudgery associated with basin digging is exacerbated by its practice during the dry season. Basin farmers are expected to start digging the basins immediately after harvest, while the soils are still moist and friable. In this case however, the basins were dug much later by which time the soils were quite dry and hard.

Table 2: Area Cultivated based on tillage System, Field data, 2009

The majority of the households (81%) reported that the area of land they allocated to CA had increased since they started practicing CA while the rest (20 %) said it had not. The reasons given for the lack of expansion in the land area under CA included; lack of labour (39%), lack of land (30%), no timely access to seed (9%), sufficient land already allocated to CA (9%), new CA farmer (9%) and farmer had been away (4%). The total area under CA was correlated with the period of time CA had been practised for each household. The correlation turned out to be very tenuous with R=0.123 (p=0.165). This showed that total area under CA did not necessarily increase with time and other factors determined the size of land that households allocated to CA.

3.1.2 Timeliness of Land Preparation

The CA Handbook for Hoe Farmers in AERs I and IIa encourages maize (*Zea mays)* farmers to "plant immediately after the first heavy rain that falls after 15th November" (CFU, 2009a:23). The same handbook advises CA farmers to plant groundnuts (*Arachis hypogaea)* at the same time as maize, while cotton *(Gossypium hirsutum)* can be dry planted any time after 8th November or immediately after heavy rains. Other crops, sorghum *(sorghum bicolor)*, millet (*Eleusine coracana)*, sunflower (*Helianthus annuus*), soya beans (*Glycine max*), cowpeas (*Vigna unguiculata*, green gram (*Vigna radiata*) and pigeon peas *(Cajanus cajan*), could be planted after heavy rains during the period 1st-15th December. This entailed that land preparation must have been done during these dates for it to have been considered timely. The results showed that only 33%, 19% and 16% of the basins, ripped areas and ploughed areas respectively were prepared on time (Table 3).

Table 3: Timeliness of land preparation by Tillage System

Late input (seed and fertilizer) acquisition continued to be a challenge for all the tillage systems. Timely access to inputs by smallholder farmers is a complex socio-political issue. Maize is a very political crop in Zambia, and has been since before the country's independence from Britain in 1964 (Deininger and Olinto, 2003) . Late input distribution makes it difficult for the farmers to take full advantage of CA. CA allows for early planting because the land is prepared prior to the rainy season, but when the inputs are distributed late, the yield benefits of CA will disappear. This problem is also connected to the dependence on hybrid maize. If composite maize varieties were used, the farmers would be able to use their own seeds instead of relying on purchasing seeds every year. This would allow for timelier planting. Such composite varieties are available in the region with high yield potential.

Smallholder farmers have become accustomed to waiting for the state subsidized inputs which are delivered to local depots every season. Even in cases where subsidized inputs were transported to the depots on time (this trend has increased for political-economic reasons), farmers still faced problems in raising the money for the inputs. This happened even when the previous farming season had been characterized by bumper harvests. Most farmers used the proceeds of their maize sales to buy household necessities, capital and luxury items without leaving enough for inputs for the next farming season. At the beginning of the season, they waited for remittances from their urban based relations, who were in many cases, struggling to make ends meet themselves and therefore did not send the money on time. The farmers would benefit from training in how to run farming as a business. With increased appreciation of the importance of re-investing in their farming enterprises great improvements could be made in their crop productivity through timely land preparation and planting.

3.1.3 Integration of Livestock

Hagblade and Tembo (2003c) and CFU (2009a) reported that farmers in Zambia lost about 1.5% of their potential maize yield for each day that maize was planted later than November 15th. Drudgery averse, labour constrained farming households restricted the area of land allocated to basins. The current study found that the use of oxen reduced weeding time by 22.6 man-days/ha when compared to hand weeding. This option may also be more culturally appropriate than asking farmers to start land preparation for next season immediately after harvest. Asking farmers to go back to the fields soon after harvest seemed somehow counter-intuitive and contrary to poor households' livelihood diversification preferences. Smallholder farmers, like other agents whose livelihoods are characterized by uncertainty, prefer to diversify their livelihood strategies by engaging in off-farm and non-farm activities. Smallholder farmers in Zambia engage themselves in economic and social activities during the post harvest period e.g. trading, fishing, re-thatching of huts, preparations for traditional harvest ceremonies, weddings, and travel to urban areas etc.

Livelihood diversification is the process by which rural households construct an increasingly diverse portfolio of activities and assets in order to survive and to improve their standard of living. This practice is pervasive and enduring in many of the poor countries that make up Sub-Saharan Africa (Ellis, 2000) . Smallholder farming in Zambia is a precarious enterprise. Its dependence on uni-modal seasonal rainfall and the market failures associated with both the input and produce side have necessitated diversification into non–farm activities as a risk reduction strategy. Having own oxen would enable farmers to prepare their land, plant and weed on time but still continue with their post-harvest non-farm activities. Although dry season basin digging relocates labour out of the peak land preparation and planting season, it does not address the labour bottleneck at weeding while the use of oxen does. Livestock would also result in production of more manure and less dependence on externally procured fertilizers. This would necessarily include finding low cost approaches for minimizing the incidences of livestock disease epidemics that have rocked Zambia's livestock sector in the two decades since the agricultural sector was liberalized.

3.2 Soil Fertility Management

No significant differences were obtained between the paired soil samples in terms of N, P, K, OC, bulk density, and Plant Available Water at 5% level of significance (Table 4). The only statistically significant differences were observed for soil reaction pH. Soils from the conventionally farmed plots were more acidic than those under CA. Since the pH values were above 5, they were not expected to reduce crop yields. Maize, cowpeas, groundnuts, soya beans and sweet potatoes tolerate pH levels greater than 5 (Aune and Lal, 1997). There are several reasons that may explain why there were no differences between the CA and CV plots. The main reason is probably that the principles of CA were not respected with regard to use of crop cover and retention of crop residues. Application of fertilizer was also the same for CA and CV and therefore no differences in soil chemical properties can be expected. It also takes time before changes in soil chemical and physical properties are observed and the minimum duration of five years was probably not enough to be able to detect differences.

Table 4: Physical and Chemical Characteristics of Soils under CA and CV

The N and OC levels were low, while the P and K levels were high for both CA and CV plots. The low levels of OC may be indicative of the almost complete lack of crop residue retention and low levels of manure application. The low N status may be explained by the low levels of nitrogen fertilizer applications and the continuous mono-cropping of maize. The similarities in the physical and chemical properties can be attributed to similar soil management practices. More integration of food legumes and nitrogen fertilizers would improve the N status of the soils. Thierfelder and Wall (2009) reported higher soil moisture in CA treatments compared to ploughing in their on-station study in Monze. Higher infiltration rates and soil moisture contents result from the absence of tillage with surface mulch (Fowler and Rockstrom, 2001) .

3.3 Weed Management

Hand hoe weeding was used as the only weed control measure by 75% (N=129) of the households. A combination of hand hoe weeding, and herbicides was used by 10 % of the households. Hand hoe weeding and cover crops were used by 7% and another 7% used the whole range of control measures including hand hoe weeding, herbicides and cover crops to control weeds. Only 1% of the households exclusively depended on herbicides. Therefore, 99% of the households employed hand hoe weeding as a weed control measure while only 18% used herbicides. Households hand weeded their fields an average of 3 times in a season (st.dev=0.96) regardless of tillage system. The recommended weeding frequencies are 3 and 4-6 for CV and CA fields respectively. Focus group discussants, interviewees and key informants all reported that the weed burden was much higher under CA than that of CV.

Weeds are a major bottleneck in annual cropping systems under CA in Zambia. CA farmers are supposed to weed frequently and timely in order to prevent weeds from producing seeds. CA fields observed during this study and anecdotal evidence showed that mature weeds with their seeds ready for dispersal were pervasive. With labour already very limited, it was difficult to frame a strategy on how farmers could allocate more of their activities towards weeding.

An opportunity, therefore, exists through the adoption of affordable and accessible labour saving technologies and integrated weed control. Weeding using herbicides, oxen and cultivator, and cover crops are viable options. GART (2007) reported that planting a cover crop (e.g. cowpea) within 10 days of the main crop resulted in effective weed suppression and high grain and biomass yields of both the main and cover crops.

3.4 Herbicides

Households using herbicides spent ZMK 20 818/ha or US$ 4.30/ha (st.dev=ZMK 39443 or US$ 8.2) on the purchase of herbicides annually. The herbicide commonly used was glyphosate (N-(phosphonomethyl) glycine, 41% active ingredient). It was sprayed 1.4 times (st.dev= 0.66) per season. Over 60% of the respondents said it was easy to use herbicides while 39 % said it was not as the herbicide was expensive, non-selective, and had complicated application instructions.

Farmers were using extremely low quantities of herbicides (0.55litres/ha) which reduced their efficacy. The recommended dosage is 4-5litres/ha. The use of muddy water from shallow wells frequented by livestock compounded the problem as glyphosate deactivates on contact with soil. Simplification of the use instructions and more farmer-training on the correct use of herbicides could go a long way in increasing herbicide usage among smallholder farmers and addressing the severe labour constraints faced by many farming households especially those without access to animal draught power.

3.5 Fertilizer Application

Households applied similar levels of fertilizer on their CA and CV plots (t=0.47, p=0.638). An average of 30kg/ha (st.dev=46.3) and 34.2kg/ha (st.dev=84.1) was applied on CA plots and CV plots respectively. Fertilizer was used by 65% of the respondents. The biggest challenge cited by 92% of the respondents was the high cost of fertilizer, followed by the perception that it damaged the soil (7%), while the rest (1%) said it was the unavailability of the measuring cup used for applying fertilizer in CA. On being asked when they applied basal fertilizer (N: P_2O:K_2O, 10:20:10) and top dressing fertilizer (46% N), their responses were as shown in Table 5.

Table 5: Timing of the application of basal and top dressing fertilizer

The farmers were also asked how they applied the fertilizer onto their CA fields. Their responses were: used one CFU No.8 Cup per plant (74%), just broadcasted the fertilizer over the field (10%), used one coke bottle cap per plant (9%), used Vaseline bottle (100ml jar) per plant (1%), 1 teaspoon per plant (4%), "eye judgment" (1%).

CFU (2009a, b) advises farmers to scatter one No. 8 cup of basal fertilizer (8 grams) at the bottom of every basin two months before planting. For ripped areas, farmers are asked to use one 100ml jar to 10 or 20 paces of furrow. This is equivalent to 125kg/ha for basins and either 100kg/ha or 200kg/ha for ripped areas depending on whether it is 10 or 20 paces that are covered. For applying top dressing fertilizer, farmers are advised to scratch a small furrow beside each maize stand with a stick and then use the No.8 Cup (6 grams) to apply the fertilizer. This must be done when the maize is at knee height. Agricultural extension messages given by the Ministry of Agriculture in Zambia are based on one nationally recommended application rate of 200kg/ ha of basal (NPK) fertilizer and 200kg/ha of top dressing fertilizer.

Comparing the farmers' practices with the recommended ones showed that over half of the respondents seemed to have correct agronomic knowledge on when to apply basal fertilizer and over three quarters knew how to apply top dressing fertilizer. Almost three-quarters (70 %) of the farmers said the quantity of fertilizer they used had reduced since they started practicing CA, 29% said it had increased while 1% said it had remained the same. It was surprising to note that 70% said they had reduced the quantities of fertilizers they used given that their application levels were only 13% of the CFU recommended optimal levels for CA and in light of the soil analysis results which revealed low levels of N. Manure was used on 44% and 31% of the fields under CA and CV respectively. It was added to the tilled fields before crops were planted by those households that had access to it. The low usage of manure was linked to its being inaccessible to households that did not own livestock and the difficulty of transporting it to fields far from homesteads.

Experiments on tillage systems and fertilizer application conducted by GART at its Chisamba and Magoye research stations over a five year period showed significant yield increases as a result of fertilizer application for all tillage systems (GART, 2000; 2001; 2003; 2007) . Smallholder farmers do not get the yield increases associated with fertilizer application as insufficient and late fertilizer application prevents them from optimizing its benefits. Access to agricultural credit and subsidized inputs by CA farmers was 46%, 38% and 28% in the 2006/7, 2007/8 and 2008/9 seasons respectively (Nyanga & Johnsen, 2010). Improving farmers' access to agricultural credit and/or subsidized fertilizer and linking them to markets would improve productivity.

3.6 Crop Residue Management

Crop residue retention is beneficial as it results in higher surface soil organic matter content and higher infiltration rates, reducing surface runoff and soil erosion significantly (Unger, 1994; Lal, 2007; Gowing and Palmer, 2008) . Field observations revealed that crop residues were not retained in the fields after harvest. The household survey and focus group discussions both identified challenges associated with retaining crop residues in the field. Crop residues were routinely fed to livestock. This was especially common in Southern and Central provinces. Even in cases where a household did not own livestock, its crop residues were still grazed by other households' free range livestock. Traditionally, all fields become communal grazing lands after harvest. Farmers cannot fence off their fields as this would not only be very expensive but would be challenged by their communities. In Eastern Province, the most important challenge was from the burning of crop residues by local people hunting for several species of mice, which are a local delicacy commonly known as *mbeba*. These rodents burrow in fields and locals hunt them by burning the residues and digging holes in fields. Hunting for mice peaks between April and November. Monitoring is difficult as most fields are quite far from homesteads. Eastern Province is unique in that communities live in large villages consisting of up to several hundred households, far from their fields. This makes it difficult for CA farmers to prevent hunters from burning their crop residues.

These hunters also dig holes in farmers' fields in their efforts to capture the mice and this destroys the CA basins.

3.6.1 "Natural" fertilizers and Selective Crop Residue Removal

Soil mining through low levels of fertilizer application and crop residue removal contribute to the low nutrient status of the soil. Nutrient mining, caused by the export of crops out of their production areas, is also compounding the challenge. "Natural" fertilizers, plants which add nitrogen to the soil through biological processes, are increasingly being promoted. The incorporation of the nitrogen fixing tree winter thorn (*Faidherbia albida)* is one option for mitigating this problem. Planting of winter thorn is already being promoted among CA farmers, and seems especially promising in the Southern Province where the tree occurs naturally and mature trees are found on significant portions of farmers' fields. An experiment conducted by GART in 2006 in which maize and cotton were planted in CA basins under canopies of 9 year old winter thorn trees and using reduced fertilizer rates of 50kg or 100kg per hectare of both basal and top dressing fertilizer gave yields of over 3tons/ha for maize meaning that winter thorn biomass contributed to the nutrient economy of the soil.

Winter thorn can be supplemented by nitrogen fixing annual crops like cowpeas, soya beans, velvet beans, sunhemp and groundnuts. However, the challenges associated with growing legumes would need to be studied. Linking farmers to stable markets and the inclusion of legume seed in the government's agriculture subsidy programme which is currently only limited to maize seed could help farmers. Another option for improving crop residue management is selective residue removal where parts of plants with greater value as feed or fuel are removed while the other parts are left on the land. Alley cropping with high value forage crops and use of alternative fuel sources could also help improve crop residue management (Unger, 1994).

3.7 Crop Rotations

It was observed during this study that most CA farmers only rotated crops on their small fields. The common trend was to divide one field (out of 4-5 that were under cultivation) into three equal portions and rotate crops there. These fields were usually demonstration plots which are locally known as "demo plots", managed under close supervision of extension officers for the purposes of demonstrating various agronomic practices to other farmers. Farmers received free inputs for these demo plots and both farmers and extension officers ensured that on these fields, farming closely resembled that found on research stations. Focus group discussants and informal chats with the farmers suggested that farmers found it difficult to practice crop rotation as recommended because they did not want to grow so much of the legumes which had no market. They preferred to plant more maize than a legume onto their 1 ha "maize field". Intercropping the maize with food legumes may be more acceptable. Linking farmers to legume markets may also change farmers' perceptions towards these crops. For instance soya beans fetched higher prices than cotton and farmers were increasingly turning to it. Providing farmers with knowledge on the other benefits of crop rotations such as breaking of disease or pest cycles should be emphasized and clearly demonstrated.

3.8 Crop Yields and Tillage systems

Results from on-station trials were better than from on-farm trials for all the four tillage systems (Table 6). The results from all the sources presented showed that basins gave the highest yield. This was despite the fact that different agronomic practices were associated with the basin tillage system. The on-station results were obtained from plots where recommended CA agronomic practices were carried out to the letter (e.g. full fertilizer recommended rates, timely planting etc). In the Langmead (2004) on-farm trials, farmers received the same quantities and types of inputs for the CV and CA tillage systems. Yields from CA fields were higher than from CV fields. However, the yield results reported under CV were higher than the average reported in literature. Mean maize yields on smallholder farms for Zambia are generally below 2 tons/ha (Xu et al, 2009; IESR, 1999; Zulu et al, 2000). These farmers had timely access to more resources than the average hand hoe farmer who fails to manage the 2.8 tons/ha that was obtained in these on-farm trials.

The higher yield results observed among CA farmers may be, as argued by Haggblade and Tembo (2003c), due to higher input use and extra extension support under CA and similar results could be obtained under CV with similar input and extension levels. This assertion may seem to have support when one looks at the relatively higher maize yields reported by the farmers in the Langmead (2004) on-farm trials from their CV fields, despite lack of access to extension services. Several of the CA fields investigated in this study were demonstration fields and their management was closely supervised by CFUs field staff.

The higher yields recorded from on- stations trials were not surprising. It has been widely documented in literature that agronomic practices that show great promise under experimental conditions at research stations fail to be replicated in farmers' fields. This is because farmers are constrained in resources, such that investment in a new technology not only influences what must be done in one field, but involves trade-offs with other activities from which the farmers generate their livelihood (Giller et al, 2006) . An obvious example of the trade-off with other livelihood activities is the digging of basins during the dry season, a period during which farmers hitherto used to engage in non-farm activities.

Table 6: Maize yields from various tillage systems from five different sources

The clear superiority of basins may be attributed to their water harvesting ability and precise and efficient input application. Basins outperformed other tillage systems *ceteris paribus.* Anecdotal reports also alluded to this. The differences between CA and CV were reportedly best seen during seasons characterized by moisture stress (Thierfelder and Wall, 2009). Oxen owning households claimed they dug "a few basins because the yields were better than from the ripped fields". Over half (59%) and 41% of households that ploughed and ripped some of their fields respectively also dug basins on other plots and attributed this to the higher yields under basins. Despite, the higher yields from basins, the area under basins was still quite small for reasons discussed in section 3.1.

3.8.1 Prospects for Promoting CA in Zambia

Conservation Agriculture is a very knowledge-intensive enterprise. Acquisition of this knowledge is a process which demands time and commitment from the would-be or the farmer already practicing CA. A lack of proper knowledge results in misallocation of inputs, poor soil fertility management resulting in low crop yields. Despite having the correct agronomic knowledge, farmers may still not adopt all the aspects of CA due to reasons that may not be immediately obvious to outsiders. Farmers have multiple social roles within and outside their households and extended families which influence their decision making processes. Some aspects of CA may conflict with these roles and lead to its low adoption. It is therefore important for CA promoters and technical experts to also acquire non-technical knowledge on the world of the farmer.

Knowledge and appreciation of local cultural practices would also result in more context -specific CA packages. Currently, CA in Zambia is being promoted in four provinces as a 'blueprint package', regardless of variations in local cultural practices. The CA package can be tailored in such a way that there are several options through which it can be adopted depending on the households' or communities' local contexts. Farmers are hungry for knowledge that can improve the fertility of their soils, increase crop yields and ensure household food security.

Promoters of CA in Zambia do not seem to be giving sufficient attention to all the different phases of the farming cycle. Introduction of CA is Zambia is not only a question of technology transfer ,but needs to address bottlenecks related to access to input, integration in markets and access to credit. There seems to be little point in dry season land preparation if the challenges of timely access to inputs and credit, the critical need for labour saving technology at weeding, and the continued low soil fertility status are not addressed. Espousing the benefits of CA with caveats (e.g. higher infiltration rates provided crop residues are retained on fields, reduced fertilizer usage provided correct input application and crop rotation etc) would draw attention to the constraints and a search for more contextually appropriate adaptations of the principles of CA.

4. Conclusions

The results on the application of Conservation Agriculture among smallholder farmers in Zambia showed that farmers are most constrained in adopting correct practices related to weed management, crop residue retention, timely planting, and soil fertility management. Further promotion of Conservation Agriculture among smallholders could benefit from addressing these constraints in ways that are sensitive to farmers' local socio-cultural contexts. Adaptation of CA to the Zambian context must include addressing constraints at all the phases of the farming cycle so that the gains made at one phase are not lost due to challenges that are faced later in the season.

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Notes

Note 1. These are the approximately 800,000 households that cultivate between 0.5-9 ha of land. They mostly produce for own consumption and lack access to functioning input and output markets and support services. Smallholders produce about 60% of the national's most important staple crop, maize (Siegel and Alwang, 2005).

Note 2. Conventional Agriculture in the Zambian case is any farming method which involves the use of hand hoe or the mouldboard plough for tillage; the routine burning, grazing or removal of crop residues; and often includes an over dominance of maize mono-cropping.

Note 3. GART is a research institution created in 1993 by the Government of the Republic of Zambia in partnership with the Zambia National Farmers Union. It places emphasis on demand-driven and adaptive agricultural research. Its current area of concentration is research and development on conservation agriculture.

Table 1. Agro-ecological Characteristics of the study areas

Study Areas	AER	Mean Annual Rainfall (mm)	Altitude (m a.s.l)	Growing season (days)	Soil types
Monze	IIa	732	1080	100-140	Lixisols, Luvisols, Alisols, Acrisols, Leptosols, Vertisols
Mumbwa		804	1102		
Petauke		932	850		
Chipata		1033	1011		
Katete		983	1060		
Sinazongwe	I	789	536	80-120	Nitosols, Luvisols, Vertisols, Arenosols, Leptosols, Solonetz

Source: Field data, 2009; adapted from Meteorological Dept, 2010; MACO/JICA, 2007

Table 2. Area Cultivated based on tillage System

Tillage type	Mean area cultivated (ha)				% of Respondents (N=129)
	Central	Southern	Eastern	Overall	
Basins	1.2*	0.6	0.6	0.8	88.4
Ripping	2.1	1.1	2.4	1.6	50.4
Ploughing	1.8	1.7	1.7	1.7	67.4
Hand hoe	1.0	0.5	1.2	1.1	25.6

*Significant at the 0.05 level ($p<0.001$)

Table 3. Timeliness of land preparation by Tillage System

Timeliness	Basins	Ripping	Handhoe	Ploughing
Early	32.8	18.9	10.0	16.0
Late	66.4	59.5	60.0	59.2
Very late	0.7	21.6	30.0	24.8
n	137	74	10	125

Note- Early: 15-30 Nov
Late: 1-14 Dec
Very Late: after 14 Dec

Table 4. Physical and Chemical Characteristics of Soils under CA and CV

	Conservation Agriculture		Conventional Agriculture		Paired T-Test (95% CI)
	Mean	Status	Mean	Status	
Total N (%)	0.12	low	0.12	low	t=0.02, p= 0.988
Organic C (%)	1.19	very low	1.22	very low	t=0.39, p= 0.695
P (mg/kg)	15.53	high	12.43	high	t=1.43, p= 0.158
K (cmol/kg)	0.75	high	0.73	high	t=0.95, p= 0.346
Bulk Density (g/cm3)	1.42	normal soil	1.44	normal soil	t=0.94, p= 0.351
Plant Available Water (v/v)	0.14	normal	0.16	normal	t=1.43, p= 0.158
pH ($CaCl_2$)	5.44	normal	5.26	normal	t=2.39, p= 0.019

Note: The statuses were categorized based on average figures for the tropics (Landon, 1984; Aune and Lal, 1997).

Table 5. Timing of the application of basal and top dressing fertilizer

Basal fertilizer	Percentage of respondents (n=83)	Top dressing fertilizer	Percentage of respondents
Before sowing	55.6	When maize at knee height	76.0
When sowing	12.5	When maize at waist height	7.6
After emergence	20.8	Just before tussling	7.6
When maize 15cm high	1.4	When maize at chest height	3.8
When maize at knee height	8.3	5 weeks after planting	1.3
When maize at chest height	1.4	3 weeks after planting	3.8

Source: Field Data, 2009

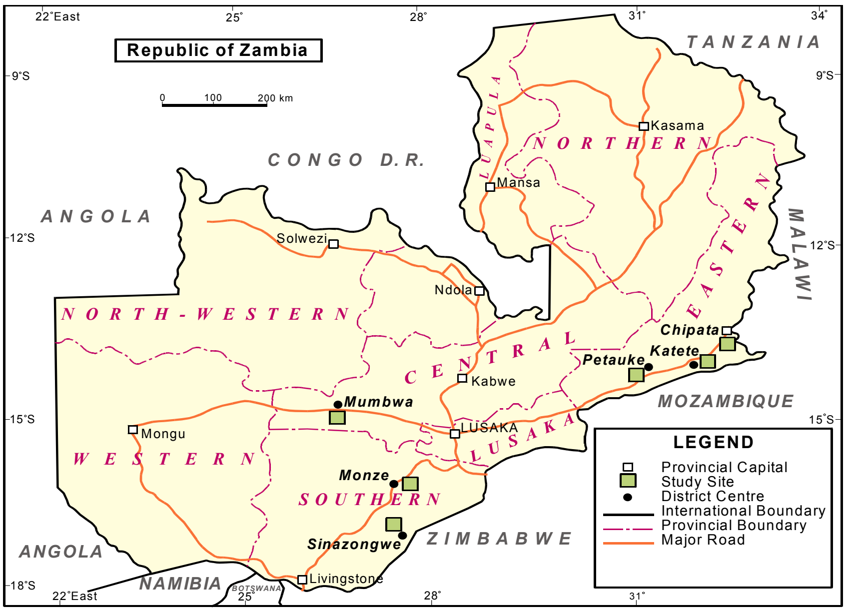
Table 6. Maize yields from various tillage systems from five different sources

Tillage System	On -station experimental results			On-farm trials	Survey results	
	GART	MFTC*		Langmead	IFPRI/FSRP	Current study
	Mean (t/ha)	Mean (t/ha)		Mean (t/ha)	mean (t/ha)	mean (t/ha)
Hand hoe	4.0	-		2.8^{a} (1.6)	3.1^{a} (1.3)	1.8^{a} (3.1)
Basins	6.3	5.5^{a}	4.9^{a}	4.8^{b} (2.1)	3.1^{a} (1.7)	5.2^{b} (3.4)
Ripping	5.3	-		-	1.7^{b} (1.2)	2.3^{a} (1.2)
Ploughing	5.5	3.6^{b}	5.2^{a}	2.4^{a} (1.0)	1.3^{b} (0.9)	3.8^{b} (4.2)
LSD (0.01)	0.9					
CV (%)	10.3					

[a] means the same column followed by the same letter were not significantly different at p≤ 0.05 probability level. ANOVA was used to test for significant differences.

*Results for 2005/2006 and 2006/2007 farming seasons respectively.

Source: Field data, 2009; GART, 2004; IFPRI/FSR, 2003, Langmead, 2004, Thierfelder and Wall, 2009



Source: Field Survey, 2010

Figure 1. Locations of the study areas in Zambia