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Precision conservation agriculture for vulnerable farmers in low-potential zones

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Abstract

ICRISAT, FAO, and Non-Governmental Organizations (NGOs) in southern Africa have been testing modifications of conservation farming techniques that create what can be called precision conservation agriculture (PCA). These strategies for farmers in low potential zones, where a majority of the most resource-poor and vulnerable farm households exist, encompass four major principles: (i) minimum tillage – for instance, using planting basins, made with a hand hoe, which concentrate limited water and nutrient resources to the plant with limited labor input, (ii) the precision application of small doses of nitrogen-based fertilizer to achieve higher nutrient efficiency (from organic and/or inorganic sources), (iii) combining improved fertility with improved seed for higher productivity, and (iv) use of available residues to create a mulch cover that reduces evaporation losses and weed growth. These basic principles are taught to farmers who choose crop mixes adapted to their local conditions and household resource constraints. PCA spreads labor for land preparation over the dry seasons and encourages more timely planting, resulting in a reduction of peak labor loads at planting, higher productivity and incomes. Over four years these simple technologies have consistently increased cereal yields by 50 to 300% in more than 50,000 farm households (with the yield increase varying by rainfall regime, soil type and fertility, and market access). Although the area under PCA is not large enough yet to create a marketable surplus, food security has increased substantially. As expected, these farmers are adopting these techniques slowly. The area to which they have applied PCA has more than doubled from 0.1 ha to 0.3 ha per farm and this small area is accounting for 35% of household cereal requirements on average. PCA also enables diversification in cropping patterns and more reliable legume production. Returns to labor have been about two times higher than conventional practices on average and making planting basins every year leads to build up of soil fertility and organic matter over time resulting in a more sustainable system.

Key words

planting basins, zai, fertilizer, farm labor, organic matter

Background

In the drier areas of southern Africa, farmers experience drought once every two to three years. Relief agencies have traditionally responded to the ensuing famines by providing farmers with enough seed and fertilizer to enable them to re-establish their cropping enterprises (UNEP 2002; MEA 2005; Cooper et al. 2008). However, because of the lack of appropriate land and crop management interventions, vulnerable farmers are not necessarily able to translate the relief into sustained gains in productivity and incomes (Rockstrom et al. 2009; Twomlow et al. 2008a).

To improve crop production in the marginal rainfall regions of southern Africa, farmers have to adopt cultural practices that conserve fragile soils and extend the period of water availability to the crop, be it grain or forage. National and international research and development organisations have mostly focused on developing improved genotypes, tillage/soil management systems, and integrated pest/disease management packages. Unfortunately, many of these outputs, although technically sound, have failed to perform well in farmers' fields. They were largely developed and tested in researcher-managed trials, with limited consideration to the problems and priorities of smallholder farmers for whom they were intended (Anderson 1992; Ryan and Spencer 2001; Shiferaw and Bantilan 2004; Twomlow et al. 2006). Unfortunately, efforts to develop African agrarian economies and achieve the MDGs must contend with the increasing challenge of climate change (see for example, Love et al. 2006; Stern 2006; UNDP 2006; Cooper et al. 2008). Most scientists now agree that global warming is inevitable, (IPCC 2007), and that it will have major impacts on the climate worldwide and agricultural productivity, particularly in sub-Saharan Africa (Tadcross et al. 2007; Cooper et al. 2008).

Conservation agriculture (CA) is being promoted as a potential solution to the production problems faced by smallholder farming families in sub-Saharan Africa (Haggblade and Tembo 2003; Hobbs 2007; Rockstrom et al. 2009). Conservation agriculture is a suite of land, water and crop management practices that aim to improve productivity, profitability and sustainability (IIR and ACT 2005). The primary principles promoted for hand-based and draft animal powered cropping systems are:

- disturb the soil as little as possible,
- implement operations, particularly planting and weeding, in a timely manner,
- keep the soil covered with organic materials (crop residues or cover crops) as much as possible, and
- mix and rotate crops (IIR and ACT 2005).

Evolution of CA in southern Africa

Conservation Agriculture is generally defined as any tillage sequence with the objective of minimising or reducing the loss of soil and water; operationally a tillage or tillage and planting combination which leaves at least 30% or more mulch or crop residue cover on the surface (SSSA 1986; IIR and ACT, 2005). In the drylands of southern Africa, CA has been loosely applied to any tillage system whose objective is to conserve or reduce soil, water and nutrient loss, or which reduces draft power (human, animal, and mechanical) input requirements for crop production. With the cropping period in most semi-arid regions being relatively short, the timing of field operations is critical.

The following CA techniques have been evaluated and actively promoted in Zimbabwe since the 1980s: no-till tied ridging; mulch ripping; no-till strip cropping; clean ripping; hand-hoeing or zero till; tied furrows (for semi-arid regions) and open plow furrow planting followed by mid-season tied ridging. These have frequently been promoted in combination with mechanical structures such as: graded contour ridges; dead level contour ridges with cross-ties (mainly for semi-arid regions); infiltration pits dug at intervals along contour ridge channels; *fanya juus* (for water retention in semi-arid regions); vetiver strips and broad-based contour ridges (mainly used on commercial farms) (Mupangwa et al. 2006; Twomlow et al. 2006).

Unfortunately, despite nearly two decades of development and promotion by the national extension program and numerous other projects, adoption of CA has been extremely low in the smallholder sector of sub-Saharan Africa, compared to other continents such as South America, North America and Europe due to various constraints (Erenstein 2003; Goddard et al. 2008; Gowing and Palmer 2008). These include: a low degree of mechanization within the smallholder system; a lack of appropriate implements; a lack of appropriate soil fertility management options; problems of weed control under no-till systems; poor access to credit; a lack of appropriate technical information for change agents and farmers; blanket recommendations that ignore the resource status of rural households; competition for crop residues in mixed crop-livestock systems, and the availability of labor (Hobbs et al. 2007; Gowing and Palmer 2008).

Despite these constraints, a number of different initiatives have recently begun to re-examine the potential for CA to improve crop production within the smallholder sector of Zimbabwe. For the purposes of this paper we have adopted the terminology of the Zimbabwe Conservation Agriculture Task Force (ZCATF), as it has been noted that many organisations use the terms CA and conservation farming (CF) interchangeably in their reports and proposals as if they were the same, yet the two are different.

- *Conservation Agriculture (CA)* is a broader term that encompasses activities such as minimum tillage and zero tillage, tractor powered, animal powered and manual methods, integrated pest management, integrated soil and water management, and includes CF. It is generally defined as any tillage sequence the objective of which is to minimize or reduce the loss of soil and water; operationally a tillage or tillage and planting combination which leaves 30% or more mulch or crop cover on the surface (SSSA 1986; IIR and ACT 2005), equivalent to more than 3 t ha^{-1} of crop residues.
- *Conservation Farming (CF)* is the particular technology developed by Brian Oldrieve using planting basins and soil cover. This is a modification of the traditional pit systems once common in southern Africa and is a variation on the *Zai* Pit system from West Africa, which may also be considered a CF technology. Both are a sub-set of the broader CA term.
- *Precision Conservation Agriculture (PCA)* is a modification of the CF- planting basin approach that includes the precision application of small doses of nitrogen-based fertilizer to achieve higher nutrient efficiency from available basal fertility amendments (from organic and/or inorganic sources) concentrated in the planting basin.

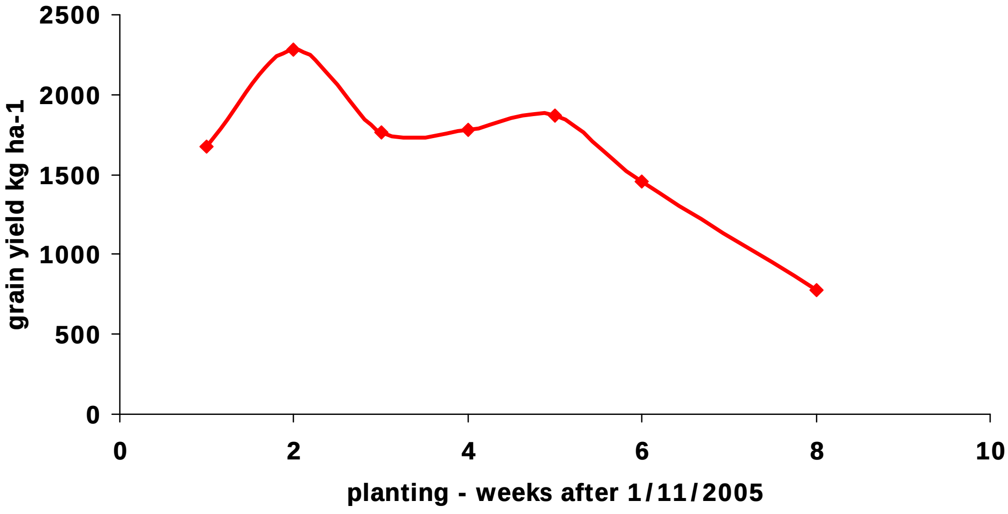
In order to ensure that a consistent message on CA was delivered by the many non-governmental organizations (NGOs) working in Zimbabwe, the United Kingdom's Department for International Development's Protracted Relief Program for Zimbabwe, on behalf of other humanitarian relief agencies, tasked the United Nations Food and Agriculture Organization Emergency Office for Zimbabwe to establish a broad-based partnership that would coordinate CA activities. The CA Task Force for Zimbabwe (ZCATF) was initiated in March 2004 and its successes to date have been summarized in Twomlow et al. (2008b).

The interventions currently being promoted/tested in Zimbabwe include:

- *Planting Basins* and *Shallow Planting Furrows* using a hand hoe,
- *Ripper* tines, attached to the beam of the animal drawn moldboard plow, to prepare planting lines in un-plowed soil for households with limited access to draft animal power; and
- *Specialised No-Till/ Direct Planting Seeders* aimed at the emerging commercial farmers with unlimited access to draft animal power.

All of these interventions are being compared with the traditionally applied practice of overall spring plowing with an animal-drawn moldboard plow and planting, sometimes referred to as 'Third Furrow Planting'. Seed is dropped into every third or fourth furrow opened by the plow (October through to December depending on the start of the wet season) when the soils have been softened by the rains. The next pass of the plow covers the seed, which is then left to germinate in a weed-free seedbed. Unfortunately, all too frequently many households with limited or no access to draft animals have to wait until better-resourced households have completed their own planting before they may borrow or hire a team of draft animals (Twomlow et al. 2006). This often means that the poorer resourced, most vulnerable households, typically plant 4 to 6 weeks later than other households. Some plantings occur as late as January, with resulting losses in yield potential. Figure 1, derived from field data collected by ICRISAT during the 2005 seasons, clearly shows the decline in yield as plantings get later and later in the season. Some may ask why land preparation does not take place in the dry season – a good question as a standing extension recommendation is to carry out winter tillage. Unfortunately, by the time all crops have been harvested and the land is ready for tillage the condition of the communal herd, which includes the draft animal resource, has declined due to a reduction in available forage.

Figure 1. Observed variation in smallholder cereal grain yield response to planting dates in southern Zimbabwe, 2005 (ICRISAT unpublished data)



The planting basins

The central component of the 'basin tillage package' is the planting basin. Seeds are sown, not along the usual furrow, but in small basins – simple pits that can be dug with hand hoes without having to plow the whole field. The technology is particularly appropriate to southern Africa, given that the majority of smallholder farmers struggle to plant their fields on time because they lack draft animals (Twomlow et al. 1999; 2006). The basin tillage concept was first developed by Oldrieve in Zimbabwe (1993), and subsequently modified and promoted in Zambia by the Zambian Farmers Union Conservation Farming Unit (Haggblade and Tembo 2003). This practice spreads labor for land preparation over the dry seasons and encourages more timely planting, resulting in reduction of peak labor loads at planting. The basic components of the CF practice agreed by the ZCATF are listed in Box 1.

Planting occurs in Nov/Dec after the basins have captured rainwater (and then drained naturally) at least once. Smallholder farmers without draft power can plant soon after an effective rainfall event,[1] rather than waiting for draft animals to become available several weeks into the season. In addition, farmers are encouraged to spread whatever crop residues might be available as a surface mulch to prevent soil losses early in the season, conserve moisture later in the season, and enrich the soil with nutrients and organic matter as the residues decompose.

When the basins are combined with the precision application of available basal soil fertility amendments and micro-doses of inorganic nitrogen fertilizer as top dressing (Twomlow et al. 2008c) it is termed 'Precision Conservation Agriculture' (PCA) irrespective of the quantity of surface residues retained as mulch.

This paper presents results from three related studies on the PCA package (basin planting plus targeted application of fertility amendments) for vulnerable households in southern Zimbabwe promoted through the relief and recovery programs operating in the country since 2004. The first study was the wide-scale testing of the PCA concept across multiple locations in southern Zimbabwe through relief and recovery programs (Hove and Twomlow 2008; Mazvimavi et al. 2007; Twomlow et al. 2007 2008d). The second study was a series of researcher-managed trials both on and off station to begin the disaggregation of the various components of the PCA package (Mashingaidze et al., 2007; Mupangwa et al., 2007). The third study focused on an initial quantification of the longer term impacts of various crop establishment practices, weeding regimes, fertilizer rates and mulching on crop yields, and water-use efficiency using systems simulation modeling.

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[1]. An effective rainfall event is 30 mm for sandy soils and 50+ mm for heavier soils (Twomlow and Bruneau, 2000).

Box 1. Components of CF Planting Basins Package promoted in Zimbabwe

1. *Winter weeding*

The first step in preparing a field using CF methods is to remove all weeds. This should be done soon after harvesting in May/June. Weeding is done using implements such as hand hoes and machetes that disturb the soil as little as possible. The importance of weeding before land preparation is to ensure that the plot is weed-free at basin preparation and also to prevent the dispersal of weed seeds.

2. *Digging planting basins*

Planting basins are holes dug in a weed-free field into which a crop is planted. The basins are prepared in the dry season from July to October. The recommended dimensions of the basin are 15×15×15 cm, spaced at either 75×60 cm for Natural Region II and either 75x75 cm or 90×60 cm for Natural Regions III, IV and V. The basins enable the farmer to plant the crop after the first effective rains when the basins have captured rainwater and drained naturally. Seeds are placed in each basin at the appropriate seeding rate and covered with clod-free soil. The advantage of using basins is that they enhance the capture of water from the first rains of the wet season and enable precision application of both organic and inorganic fertilizer as it is applied directly into the pit and not broadcast.

3. *Application of crop residues*

Crop residues are applied on the soil surface in the dry season, soon after harvesting. The residues must provide at least 30% soil cover. The mulch buffers the soil against extreme temperatures (thereby reducing soil evaporation), cushions the soil against traffic, and suppresses weeds through shading and improves soil fertility.

4. *Application of manure*

Fertility amendments are applied soon after land preparation in the dry season. In CF, the application of both organic and inorganic fertilizers is recommended as they complement each other. Organic fertilizers such as manure and/or composts are applied at a rate of at least a handful per planting basin. More can be used in wetter areas.

5. *Application of basal fertilizer*

Inorganic basal fertilizer is also applied soon after land preparation before the onset of the rains. One level beer bottle cap is applied per planting basin and covered lightly with clod-free soil. This is equivalent to 80 kg of compound fertilizer per hectare. Application rates can be increased in wetter areas and may depend on crop types.

6. *Application of topdressing*

Nitrogen fertilizer is applied to crops at the 5 to 6 leaf stage soon after the first weeding at a rate of one level beer bottle cap per basin. This is equivalent to 80 kg of ammonium nitrate fertilizer per hectare. Application is done on moist soils. Precision application ensures that the nutrients are available where they are needed. Application rates can be increased in wetter areas and may depend on crop types.

7. *Timely weeding*

In conventional tillage systems, farmers plow/cultivate repeatedly in order to suppress weeds. With reduced tillage, weeds can be a problem requiring more effort initially. One strategy is to weed in a timely manner (ie, when the weeds are still small) preventing the weeds from setting seed. Timely weeding in combination with mulch should eventually lead to effective weed control.

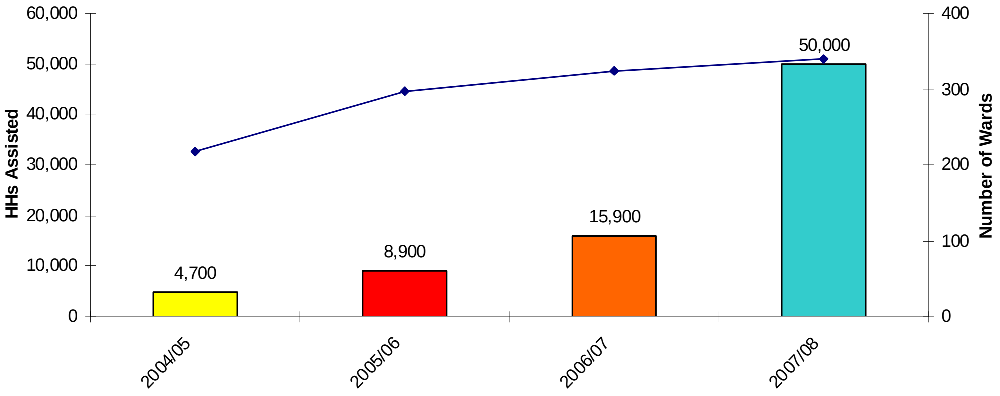
8. *Crop rotation*

Rotating crops is one of the key principles of CF. Cereal/legume rotations are desirable because the cereal benefits from nitrogen produced by the Rhizobium associated with the legume, and the legume benefits from the residues produced by the cereal. The advantages of crop rotation include improvement of soil fertility, controlling weeds, pests and diseases, and producing different types of outputs, which reduce the risk of total crop failure in cases of drought and disease outbreaks.

Study 1: Gains to vulnerable households from PCA through 4 years of field testing

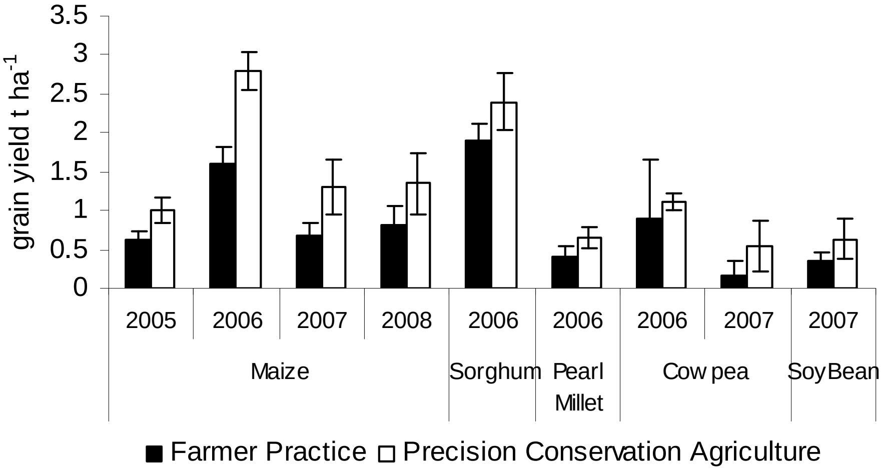
The PCA concept was introduced by NGOs and donors with technical assistance from ICRISAT in 2004/05 to a very small group of farmers. Since then the number of farmers practicing PCA has increased significantly over the intervening seasons (Figure 2). Over the fours seasons for which data are available from a nationwide system of 0.2 ha paired plots (0.1 ha under basins and 0.1 ha under traditional farmer practice), the basin package has consistently increased average cereal yields by 50 to 300% (Figure 3) in more than 50,000 farm households, with the observed yield increase varying by rainfall regime, soil types, fertility and farmers resource status.

Figure 2. Promotion of PCA in Zimbabwe between 2004 and 2008 showing the number of households receiving seed, fertilizer and technical support each season through the relief programs and the number of wards the NGOs are active in (adapted from Twomlow et al., 2008



DATA Source: FAO Database, NGOs
Map Production: FAO
Shape Files: CSO & SG

Figure 3. Cereal and legume grain yield responses to conventional farmer practice and PCA (planting basins) over three seasons averaged across 13 districts in semi-arid in Zimbabwe. Error bars represent the standard error of differences between the means of the treatments for each crop in each season of observation. (Source: ICRISAT, Bulawayo unpublished data)



Use of volunteer farmer clusters, rather than lead farmers or farmer field schools to demonstrate these principles, is leading to higher spontaneous uptake (Mazvimavi et al. 2007). For instance, in two wards in southern Zimbabwe, where paired plot demonstrations were established on less than 10% of farms, more than 1000 farm households have since invested their own capital and other resources, representing spontaneous uptake by nearly 90% of the population. Although the area under PCA is not large enough yet to create a marketable surplus, food security has increased substantially. As expected, farmers are adopting these techniques incrementally (Mazvimavi and Twomlow 2009). The area under PCA has doubled from around 0.1 ha per farm in 2004 to more than 0.3 ha per farm in 2008 (ICRISAT unpublished survey data), and this small area is accounting for 35% of household cereal requirements on average.

Precision conservation agriculture also enables diversification in cropping patterns and more reliable legume production. Returns to labor have been about two times higher than conventional practices on average (Table 1). Although making the basins requires time and effort, once prepared, the same planting position can be used repeatedly. With each successive season preparing the basins and weeding should become easier. Maintaining all other production costs constant, CF remains more profitable than conventional farmer practice, even when significant yield gains can be achieved from farmer practice in higher rainfall conditions with fertilizer use (Mazvimavi and Twomlow 2009).

Table 1. An enterprice analysis for PCA versus Traditional Farmer Practices under high-, normal-, and low-rainfall situations in Zimbabwe (microdosing with 28 kg N ha^{-1}) (adapted from Mazvimavi and Twomlow, 2009 based on survey data collected in April 2007).

		PCA		**Traditional farmer practice**	
		First year	**Second + year**	**No fertilizer**	**With fertilizer**
High rainfall					
Maize grain	kg ha^{-1}	2000	2650	678	1120
Gross margin	US$ ha^{-1}	654	867	197	357
Cost per kg	US$ kg^{-1}	0.07	0.07	0.15	0.12
Returns to labour	US$ day^{-1}	6.3	7.0	3.3	4.9
Normal rainfall					
Maize grain	kg ha^{-1}	1750	2200	560	728
Gross margin	US$ ha^{-1}	529	697	153	19
Cost per kg	US$ kg^{-1}	0.10	0.08	0.17	0.18
Returns to labour	US$ day^{-1}	5.5	6.3	3.0	3.3
Low rainfall					
Maize grain	kg ha^{-1}	1520	1780	368	400
Gross margin	US$ ha^{-1}	473	535	71	48
Cost per kg	US$ kg^{-1}	0.09	0.10	0.25	0.32
Returns to labour	US$ day^{-1}	5.2	5.3	1.9	1.5

These swift yield gains from planting basins are achieved because the technology enables farmers to plant and carry out all field operations in a timely manner.[2] The concentration of water and available soil fertility amendments within the planting basin is reducing the risk of crop failure, even under drought conditions.

It is estimated that throughout most of Zimbabwe, irrespective of rainfall regimes, if a household were to devote at least 0.6 ha to CA it would meet their basic cereal requirements in all but the worst rainfall season, with many seasons producing a surplus (Mazvimavi et al. 2007). This would then allow farmers to diversify the crops they are growing on the rest of their land holdings, making crop rotations feasible and giving many option of cash crop production and sustainable livelihood improvement and commercialisation. Additionally, yield increase and stabilisation will produce more biomass for mulching and/or stockfeed.

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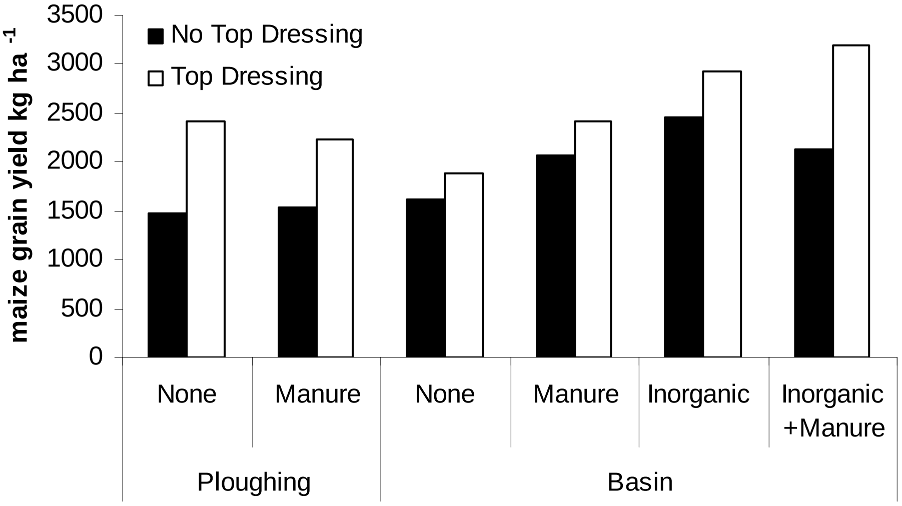
[2] Generally farmers depend on third party tillage (plowing) of their land. In CF farmers can prepare their plots by hand in the off-season. Delayed planting after the optimum planting date reduced the yield potential by around 30% per month.

Study 2: Disaggregation of the basin planting package

Impact of fertilizer amendments on maize yield responses

The impact of basal and top dressing fertility management regimes on maize grain yield responses to basin tillage and conventional spring plowing are summarized in Figure 4.

Figure 4. The impact of basal fertilizer only (filled bars) and combined with top dressing fertilizer open bars) regimes on maize grain yield responses to basin tillage compared with traditional spring plowing for 11 districts in southern Zimbabwe in the 2005/06 season.



There is a strong interaction between basal fertilizer application, top dressing and tillage system. Without any form of basal fertility amendments the basin tillage systems performed only slightly better than the farmers' traditional spring plowing – 1621 kg ha^{-1} compared to 1476 kg ha^{-1}. However, from Figure 4 it is clear that when farmers have access to a combination of manure and inorganic fertilizers, particularly inorganic fertilizer for top dressing, then significant grain yields can be achieved. Top dressing with inorganic nitrogen fertilizer increased yields by more than 30%. Thus, for smallholder farmers to derive long-term yield benefits from the basin tillage technique beyond the current relief and recovery programs, additional investment will be required to ensure that smallholder farmers have access to inorganic fertilizers locally, particularly inorganic nitrogen-based fertilizers for top dressing.

Effects of crop residue mulch on weed density and crop yields

High weed infestation is one of the major constraints facing farmers converting from conventional tillage to CA. Under conventional tillage, weeding labour accounts for more than 60% of all costs for producing a maize crop (Ellis-Jones et al. 1998). Smallholder farmers would welcome a reduction in weed pressure as out migration of males in search of off farm income and the HIV/AIDS pandemic in sub-Saharan Africa has exacerbated household labor shortages in the smallholder sector (Gowing and Palmer 2008). Unfortunately, very little research has been undertaken to assess the impacts of mulching on weed ecology. Data presented by Nyagumbo (1999) showed no reduction in weed pressure with mulching when maize was grown using the ripper tillage. However, recent studies by ICRISAT have shown that as the amount of maize residues is increased, mulching significantly reduced (P=0.01) weed pressure when maize was grown using planting basins at Matopos Research Station (Table 2). Similarly, the average soil water content in the top 15 cm of the profile was observed to significantly increase (P=0.01) with increasing mulch rate.

Table 2. Effects of applying graded levels of mulch on soil moisture, weed density and maize yields on a sandy soil at Lucydale, Zimbabwe, during the 2004/05 season (Adapted from Mupangwa et al., 2007).

Mulch rate (t/ha)	Average soil moisture content(%) 0–15cm depth for the 2004/05 season	Weed count (Weed m^{-2})	Maize yields (kg/ha)	
			Grain	Stover
0	4.14	14.7	478	1296
0.5	3.68	16.0	438	1235
1	3.45	17.3	521	1327
2	4.75	13.7	615	1466
4	4.52	12.0	633	1497
8	6.66	7.3	653	1491
10	6.73	5.0	599	1451
s.e.d	1.072	3.54	233.2	431.6

However, for this sandy soil, the significant reduction in weed density and increase in soil water content, observed with increasing mulch rate, were not translated to significant increases in stover and grain yields (Table 2). Similar lack of impacts of increasing mulch rates on crop yields have been observed for subsequent seasons (Mupangwa pers. comm.).

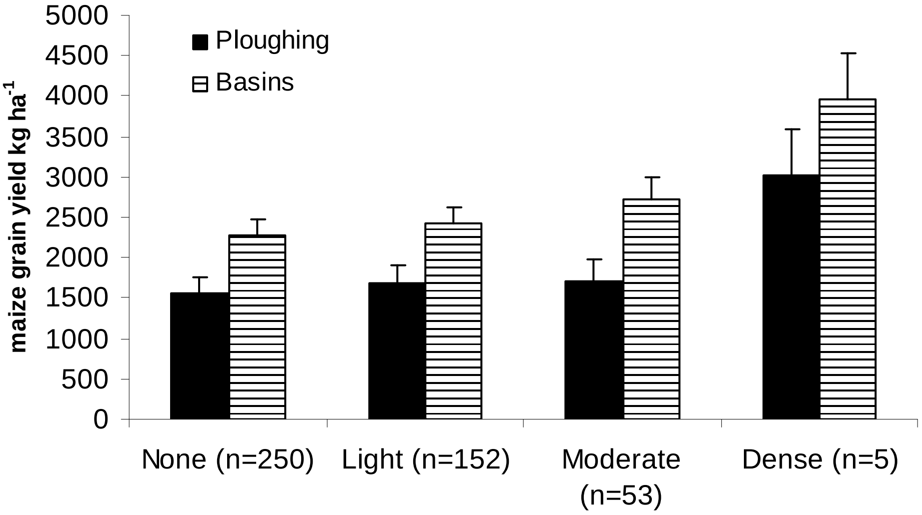
Two experiments were also conducted at West Acre (clay) and Lucydale (sand) in Matopos Research Station to determine the effect of different levels of residue retention on crop and weed growth over two seasons (Mashingaidze et al. undated). On both soil types, retaining the entire residue produced neither increased crop yield (Table 3) nor suppressed weeds (data not shown), which is to be expected given the small quantity of residues available in these environments.

Table 3. Maize yield (t ha^{-1}) responses to maize residue retention across two seasons for two sites with different soil types at Matopos Research Station

Site	West acre (Clay loam)				Lucydale (Sandy loam)			
Residue retention (%)	2004/05		2005/06		2004/05		2005/06	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
0	2.02	2.34	4.94	3.88	1.51	1.60	0.87	1.00
25	1.69	2.14	3.72	2.71	2.25	1.72	1.03	1.07
50	1.87	2.68	4.12	3.62	0.93	0.99	0.94	0.60
75	1.74	2.34	3.95	3.56	1.96	1.83	1.41	1.25
100	2.04	2.18	3.02	3.51	1.89	1.40	1.14	0.93
s.e.d	0.415	0.401	0.709	0.957	0.695	0.608	0.310	0.353

Additional data from 508 farmers implementing the basin technology across 11 districts of southern Zimbabwe showed no significant benefits of mulching with up to 3 t ha^{-1} stover during the first two seasons of implementation (see Figure 5 for the 2005/2006 average rainfall season.). Increased yields were only observed when farmers mulched their own fields with 6 t ha^{-1} or more of crop and plant residues. Smallholder farmers rarely achieve this level of stover production. Also, it is still questionable how much mulch farmers will retain on their fields, given that a major source of household income in these mixed crop-livestock systems is from the sale of goats and sheep (ICRISAT unpublished data).

Figure 5. The impact of mulch cover of various levels on maize yield in response to basin tillage compared with conventional spring plowing for 11 districts in southern Zimbabwe in the 2005/06 season. Light – less than 1 t ha^{-1}, moderate – 3 t ha^{-1} (the target), and dense – more than 3 t ha^{-1}. Error bars represent the standard error of differences between the means of the tillage practice for each mulch rate.



Unfortunately, some organizations that are currently promoting CA, are encouraging their collaborating farmers to harvest what ever sources of plant residues that might be available from the communal resource base, in an effort to achieve the 3 plus t ha^{-1} of mulch advocated by the Global CA constituency. This is done without any due consideration of the potential social conflicts that might occur between households that have a strong bias to livestock production and those that are adopting CA.

Study 3: Evaluation of effects of CA technologies on land and water productivity using the APSIM model

This exercise was carried out with the objective to disaggregate conservation agriculture (CA) technologies and understand their effects on crop grain and stover yield and also on the soil water balance (runoff, drainage and evaporation). The simulation tool used was the Agricultural Production Systems Simulator (APSIM) model (Keating et al 2003). Analyses have been done for both a clay loam and sandy loam soil types, typical of southern Zimbabwe using a 38 year (1962–1999) weather record collected by the national Weather Bureau for Matopos Research Station The model is useful in capturing the interactions between climatic conditions, soil types and nutrient dynamics (Delve and Probert 2004; Ncube et al., 2008), and weed management (Robertson et al. 2005; Shamudzarira and Robertson 2002), and has been successfully used in the cereal based farming systems of southern Africa (Whitbread et al. 2004; Ncube et al., 2008). A short-duration maize variety (SC403) was used to simulate maize growth and development to various crop production scenarios. The four main crop production scenarios simulated are as follows:

1. *Farmer practice* – crop planted using overall spring plowing from mid December through to late January, followed by a single weeding 35 days after sowing (typical scenario for farmers with limited or no access to draft animals) (FP1weed)
2. As for farmer practice, but with two weedings at 25 and 50 days after planting (FP2weed)
3. Basin planting without residues with a planting window set 20 November – 31 December and two weedings at 25 and 50 days after planting (Basins) – equivalent to PCA.
4. As for basins but with crop residues applied at a rate of 3 t ha^{-1} which represents 30% soil cover applied on 19 November each year.

Superimposed on the four crop production practices were four fertilization routines

1. No soil fertility amendments (zero nitrogen)
2. Basal fertilizers applied at planting, equivalent to 7 kg N ha^{-1}
3. Top dressing with ammonium nitrate fertilizer equivalent to a rate of 28 N kg ha^{-1} (micro-dosing) applied 35 days after planting (Top Dress)
4. Basal and Top Dressing applied (35 kg N ha^{-1}).

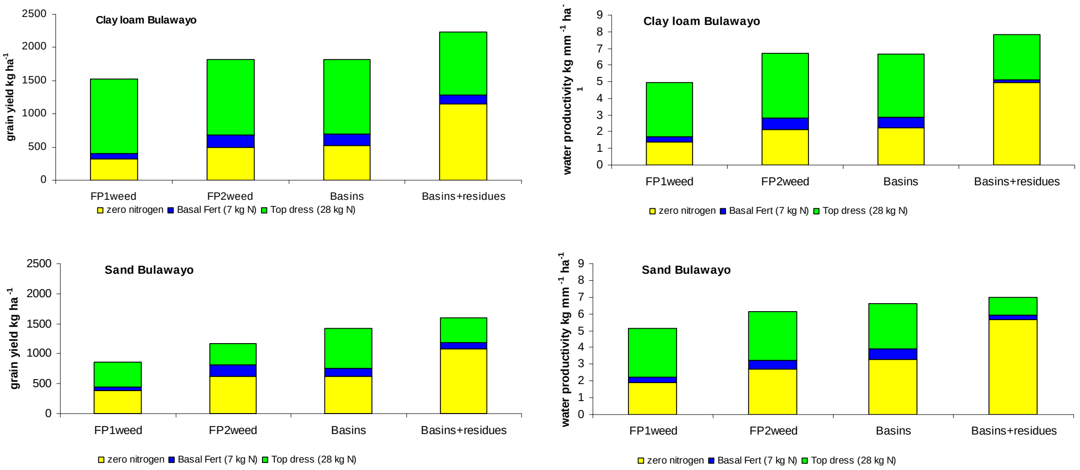
Full details of the models parameterization for these soil types are available on request.

A total of 16 treatment combinations were simulated for each site for the 38 year period.

Average simulated incremental yield responses for the four fertilization regimes superimposed on the four crop production practices and associated water productivities with respect to evapotranspiration (WP) are summarized in Figure 6. As might be expected from the literature, the highest yields and WPs for both soil types are observed for the Basins+residues, with the lowest yields and WP observed on the FP1weed. This is in contrast to the field observations made to date, which suggest that residue retention below 3 tons ha^{-1} in the short term does not have a positive effect on crop yields (Tables 2 and 3; Figure 5). However, the question remains – "Is the incremental grain yield increase observed between Basins and Basins+Residues of 400 kg ha^{-1} for the clay loam, and 180 kg ha^{-1} for the sandy soil, enough to compensate the farmer for loss of animal feedstuffs?". The largest incremental yield gain across the four crop production practices was achieved through the targeted (point application near the plants) application of 28 kg N ha^{-1} 35 days after planting.

Basin tillage with or without residues offers an opportunity for poor vulnerable households with no access to draft power to produce as much if not more grain per unit area than households with full draft power in the drier areas of Zimbabwe. Furthermore, if the access to nitrogen fertilizer can be improved there is a great chance that households will move from a food insecure state to one of surplus.

Figure 6. Mean simulated incremental yield responses and associated water productivities for four crop production scenarios (FP1weed, FP2weed, Basins, Basins+residues) with four different superimposed fertilization regimes (Zero N, 7kg N, 28kg N, 35kgN). Means of 38 years of simulation runs.



Conclusions

PCA spreads labor for land preparation over the dry seasons and encourages more timely planting, resulting in a reduction of peak labor loads at planting, higher productivity and incomes. Over four years these simple technologies have consistently increased cereal yields by 50 to 300% in more than 50,000 farm households (with the yield increase varying by rainfall regime, resource status of the household, soil types and fertility, and market access). Although the area under PCA is not large enough yet to create a marketable surplus, food security has increased substantially. As expected, these farmers are adopting these techniques slowly. The area to which they have applied PCA has more than doubled from 0.1ha to 0.3 ha per farm and this small area is accounting for 35% of household cereal requirements on average. PCA also enables diversification in cropping patterns and more reliable legume production. Returns to labor have been about two times higher than conventional practices on average and making planting basins every year leads to build up of soil fertility and organic matter over time resulting in a more sustainable system.

While PCA promises to have potential to increase productivity of the crop-livestock systems in the smallholder sector of southern Africa, the promotion of the four principles should be sequenced in a manner that reflects the social, economic and biophysical constraints that these smallholder farmers face. Currently, crop residues are extensively used as feed and using them as mulch is bound to be unacceptable to farming communities as a whole in the short term. It is proposed that when promoting PCA in these systems, the initial focus should be on raising the productivity of the systems through the optimization of other management variables: planting on time, efficient use of organic and inorganic fertility amendments and effective weeding. When adequate crop residues for feed and mulch are produced, mulching can be encouraged in a sustainable manner.

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