

Positive Aspects of Conservation Agriculture

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Abstract: A multi-pronged approach was adopted in gathering data for this study. Information sources included the Internet, agency and departmental reports, journal papers, conference papers and analytical reports. This paper presents some positive aspects of conservation agriculture. Conservation agriculture has emerged as an alternative to conventional agriculture. The rationale or case for CA is its potential ability to reduce soil degradation through several practices that minimize the alteration of soil composition and structure. It specifically purports to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil, and reduce crop production, productivity and sustainability. CA also increases farm financial profitability and food security and enhances environmental integrity. Potential economic benefits associated with CA include a reduction in on-farm costs and an increase in yields and long-term yield stability. Ecosystem benefits of CA include stabilization of soils and protection from erosion, reduced siltation of water bodies, recharge of aquifers, and more regular river flows. CA also mitigates climate change by carbon sequestration in soils and reduced burning of crop residues. Constraints to CA adoption in sub-Saharan Africa include a low degree of mechanization within the smallholder farming 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 labour shortages. There appears to be considerable potential for adoption of CA under smallholder farming systems in sub-Saharan Africa. However, the only feasible way to tap that potential appears to rest with the establishment and implementation of appropriate policy initiatives that address ecological, financial and socio-economic constraints facing the smallholder farming sector.

Keywords: conservation agriculture, soil degradation, soil composition, soil structure, economic benefits, productivity, profitability, sustainability

1. Introduction

Conservation agriculture (CA) was born out of the United States' dust bowl of the 1930s and is widely practiced in large scale commercial agriculture in North America, Brazil, Australia, Argentina, Paraguay, and increasingly in Europe, China and India (Wagstaff and Harty, 2010). The current focus of research is on adapting CA to the needs of smallholder farmers in Africa, Asia and South America who lack the resources to effectively undertake CA, particularly mechanization.

2. Defining Conservation Agriculture

In general, CA includes any practice that reduces, changes or eliminates soil tillage and avoids the burning of residues in order to maintain adequate surface cover throughout the year (ECAAF, 2001). In contrast, conventional forms of agriculture regularly use ploughs to enable deep tilling of the soil (FAO, 2001b).

Conservation agriculture is generally defined as any tillage sequence that minimizes or reduces the loss of soil and water, and is operationally tillage or tillage and planting combination, which leaves at least 30% or more mulch cover on the surface (SSSA, 1986; IIR and ACT, 2005). In the drylands of southern Africa, CA has been loosely defined as any tillage system that conserves or reduces soil, water and nutrient loss, or reduces draft power (human, animal and mechanical) input requirements for crop production (Twomlow et al., 2006).

3. Rationale for Conservation Agriculture

Conservation agriculture (CA) has emerged as an alternative to conventional agriculture as a result of losses in soil productivity due to soil degradation (e.g. erosion and compaction) (FAO, 2001a). CA aims to reduce soil degradation through several practices that minimize the alteration of soil composition and structure and any effects upon biodiversity. It specifically aims to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil. Moreover, it purports to address the problem of intensive labour requirements in smallholder agriculture (African Conservation Tillage Network, 2008). The challenge in Zimbabwe's smallholder's sector is to raise the productivity of the staple cereal as a way of solving food insecurity problems. The per capita maize production is steadily declining, and this has been attributed to significant decline in yields over the years (GOZ, 2002).

Conventional agriculture, either by hand or using a tractor, draft power and plough, leads to reductions in soil fertility and its physical deterioration. Continually inverting the soil dries it out and destroys its natural structure. The soil becomes prone to wind and water erosion and, in the tropics in particular, ultraviolet radiation from the sun kills beneficial microbes. Repeated passes, especially with mechanized traction, leads to the formation of a plough pan, a hard layer which roots cannot penetrate and which may impede drainage. Conventional ploughing is very fuel and labour intensive and therefore limits participation by the poor, sick and elderly farmers (Wagstaff and Harty, 2010).

Similar to most parts of sub-Saharan Africa, agricultural productivity levels in Zimbabwe have fallen due to land degradation, as a result of many years of erosive cultivation

and declining soil fertility as farmers fail to replenish soil fertility (Mano, 2006). As part of the relief and recovery programs, research and development initiatives have seen the introduction of a specific set of technology options that aim to improve and stabilize crop yields while preserving soil and water, and using precision methods to apply inputs. This set of technology options is defined as conservation agriculture (CA) (Thierfelder and Wall, 2010; Twomlow et al., 2008).

Proponents of CA suggest that it offers a solution to these problems by providing the means that can prevent further destruction of precious soils, increase rainwater use efficiency and labour productivity, thereby ensuring higher and more stable yields while reducing production costs. Given the continuing poor productivity of smallholder agriculture in sub-Saharan Africa and the alarming reports of soil degradation due to nutrient depletion and soil erosion (Stoorvogel and Smaling, 1998), CA appears to offer great potential to address these problems.

Zero tillage was born out of a necessity to combat soil degradation and has been widely adopted by farmers in different scales in North and South America (Bolliger et al., 2006; Triplett and Warren, 2008). Brazil's "Zero-tillage revolution" in particular, is viewed as an attractive potential solution to reversing soil degradation and increasing land productivity in sub-Saharan Africa (Fowler and Rockstrom, 2001; Hobbs, 2007).

CA was originally developed to prevent soil erosion and the practice has a number of environmental benefits that help buffer farmers from the effects of climate change. The improved soil structure, mulching with crop residues, and associated increase in soil organic matter improve rainwater infiltration and reduce evaporation from the soil. The higher waterholding capacity of the soil enables crops to reach maturity using residual soil moisture even if rains depart early in the season (Wagstaff and Harty, 2010).

Following repeated bouts of severe food insecurity in Africa, several development agencies prescribed conservation agriculture as a promising response to declining yields that is suitable for drought-prone communities (Hobbs, 2007).

4. Principles of Conservation Agriculture

Conservation agriculture (CA) is a suite of land, water and crop management practices that aim to improve productivity, profitability and sustainability (IIR and ACT, 2005).

Zero or minimum tillage, direct seeding and a varied crop rotation, are important elements of CA (FAO, 2001a). Conservation agriculture also conserves soil and terrestrial biodiversity (FAO, 2001a). CA maintains a permanent or semi-permanent organic soil cover consisting of a growing crop or a dead mulch (FAO, 2001a). The function of the organic matter is to physically protect the soil from the sun, rain and wind and to feed soil biota. Eventually, the soil micro-organisms take over the tillage function and soil nutrient balancing, thereby maintaining the soil's capacity for self-recuperating (FAO, 2001a). Residue-based zero tillage with direct seeding is perhaps the best example of

CA, since it avoids the disturbance caused by mechanical tillage (FAO, 2001a). A varied crop rotation is also important to avoid disease and pest problems.

The FAO (2001a) outlines the following examples of CA: direct sowing/direct drilling/no tillage; ridge-till; mulch till/reduced tillage/minimum tillage; and cover crops. In the practice of direct sowing and no tillage, the soil remains undisturbed from harvest to planting except for nutrient injection. Weed control under direct sowing is primarily by herbicides with little environmental impact. In the practice of ridge-till, planting takes place in a seedbed prepared on ridges, and residue is left on the surface between ridges, and ridges are rebuilt during cultivation. In mulch till, reduced or minimum tillage the soil is disturbed prior to planting, and weed control is by herbicides and/or cultivation. The practice of cover crops involves sowing appropriate crop species other than the main crop as a measure to prevent soil erosion and to control weeds.

In southern Africa the primary principles promoted in CA for hand-based and draft animal powered cropping systems are to 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); and mixing and rotating crops (IIR and ACT, 2005). 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 tillage, tied furrows (for semi-arid regions) and open plough furrow planting followed by mid-season tied ridging (Nyagumbo, 1998; Mupangwa et al., 2006; Twomlow et al., 2006). These have frequently been promoted in combination with mechanical structures such as graded contour ridging, dead level contour ridging with cross-ties (mainly for semi-arid regions), infiltration pits dug at intervals along contour ridge channels, and vetiver strips and broadbased contour ridges (mainly used on commercial farms) (Twomlow and Hagmann, 1998; Mupangwa et al., 2006).

Despite the constraints faced in the smallholder sector in Zimbabwe, a number of different initiatives have recently begun to re-examine the potential for CA to improve crop production within that sector. The interventions currently being promoted/tested in Zimbabwe include basin tillage and shallow planting furrows (using a hand hoe); ripper tines (attached to the beam of the mouldboard plough to prepare planting lines in unploughed soil for households with draft power); and specialized no-till/ direct planting seeders (aimed at the emerging commercial farmers with draft power) (Twomlow et al., 2008). Additional techniques being promoted by international relief agencies and non-governmental organizations (NGOs) in Zimbabwe include winter weeding; application of crop residues; application of manure; application of basal fertilizer; application of top-dressing fertilizer; timely weeding; and crop rotation (PRP, 2005).

5. Benefits of Conservation Agriculture

Conservation agriculture (CA) aims to make better use of agricultural resources through the integrated management of

soil, water and biological resources, combined with limited external inputs (FAO, 2001a). It contributes to environmental conservation and to sustainable agricultural production by maintaining a permanent or semi-permanent organic soil cover. Other benefits attributed to CA at the watershed level relate to more regular surface hydrology and reduced sediment loads in surface water (FAO, 2001a). At the global level, CA sequesters carbon, thereby decreasing CO₂ levels in the atmosphere and helping to dampen climate change (FAO, 2001a).

Potential economic benefits associated with conservation agriculture include reduction in on-farm costs, implying savings in time, labour and machinery. There is also an increase in soil fertility and retention of soil moisture, resulting in long-term yield increase, decreasing yield variations (more stable yields), and greater food security. CA results in stabilization of soils and protection from erosion, leading to reduced downstream sedimentation. River flows become more regular, flooding is reduced, and dried wells begin to re-emerge in areas where CA is practiced. As a result of better infiltration, aquifers are recharged. Finally, carbon sequestration and reduced burning of crop residues result in reduced emissions of CO₂ into the atmosphere, thereby mitigating global warming and climate change (FAO, 2001a).

In the absence of sustainable soil management practices such as those practiced under CA, soil degradation can lead to crop and livestock losses, with regional or global consequences such as famines and refugees. Land under CA supports terrestrial wildlife and soil micro-fauna that are important components of biodiversity, as demonstrated by the discovery of penicillin and streptomycin. Thus, good soil conservation and management under CA can have benefits that the individual farmer does not anticipate, but which have real implications for the global environment (Scherr, 1999).

Where the ecosystem function of the soil is to support wildlife habitat, the potential consequences of non-use of CA and resultant soil degradation is loss of important biodiversity. Where the function of the soil is to act as a source of micro-nutrients for human consumption (e.g. food quality), dietary deficiencies and diseases can result from soil degradation if CA practices are not implemented. If the main functions of the soil are buffering and moderation of the hydrological cycle (e.g. drainage, temporary water storage) and watershed protection, non-use of CA and the resultant soil degradation can lead to problems of flooding, soil transport and sedimentation in water bodies. In addition, poor infiltration can lead to reduced crop yields. (Scherr, 1999).

In Brazil, over a 17-year period, maize and soya bean yield under CA increased by 86% and 56% respectively, while fertilizer inputs for those crops fell by 30% and 50% respectively. In addition, soil erosion in Brazil fell from 3.4 – 8.0t/ha under conventional tillage, to 0.4t/ha under no-till, and water loss fell from approximately 990t/ha under conventional agriculture to 170t/ha under CA. (FAO, 2001a). The financial benefits for farmers in Latin America

who have adopted CA have been striking. However, the benefits take long to materialize.

To improve crop production in the marginal areas 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 (Gollifer, 1993; Twomlow and Haggmann, 1998). Conservation agriculture is being promoted as a potential solution to the production problems faced by smallholder farming families in sub-Saharan Africa (Hagblade and Tembo, 2003; Hobbs, 2007).

In Zimbabwe's smallholder sector, although the area under precision conservation agriculture (PCA) is not yet large enough to create a marketable surplus, food security has increased substantially (Twomlow et al., 2008). Precision conservation agriculture also enables diversification in cropping patterns and more reliable legume production. Returns to labour have been about twice higher than conventional practices. Maintaining other production costs constant, conservation agriculture remains more profitable than conventional practices. It is estimated that in most Natural Regions in Zimbabwe if a household devotes at least 0.6 hectares to CA it would meet their basic cereal requirements (except during drought), with many seasons producing a surplus (Mazvimavi et al., 2007). The yield increase under CA and more stable yields will produce more biomass for mulching and/or stockfeed. Precision conservation agriculture has increased average cereal yields by 50%-200% (Twomlow et al., 2008).

Hassane et al. (2000) evaluate the impact of planting basin and use of fertilizer and manure on millet crops in Niger. Their study finds that there were significant yield gains of up to 511% over a five year period. Similarly, significant yield gains are also noted in a study in Zambia by Hagblade and Tembo (2003) who note that farmers who dug planting basins and applied crop residues and fertilizers achieved 56% yield gains in their cotton fields and 100% yield gains in their maize fields. In Gokwe District of Zimbabwe, Wagstaff and Harty (2010) find that poor farmers who adopted CA achieved significantly higher maize production than traditional farmers. A follow-up study in 2009 found that CA farmers in these semi-arid districts were producing an average of between 3-6 tonnes/ha. These farmers were no longer production-deficit households but production-surplus households. Mazvimavi et al. (2012) demonstrated significant yield gains for farmers practicing CA, and significant contributions to food production.

6. Comparison of Conservation Agriculture with Conventional Agriculture

The conventional farmer believes that tilling the soil will provide benefits to the farmer, and would increase tillage if economically possible. On the other hand, the CA farmer questions the necessity of tillage in the first place and feels uncomfortable when tillage occurs (FAO, 2001a). Unfortunately, farmers tend to respond to short-term solutions and immediate benefits, yet the full technical and economic advantages of conservation agriculture can be seen only in the medium to long term when its principles are well established in the farming system (FAO, 2015). In fact,

if the two systems (conventional agriculture and conservation agriculture) are applied in two plots with the same agro-ecological and fertility conditions, no great differences in productivity during the first few years are to be expected. However, after cultivating the crops in the same areas for several years, the differences between the two systems become more evident (FAO, 2015). Crop production profitability under CA tends to increase over time relative to conventional agriculture (FAO, 2001a).

Stonehouse (1997) simulated full-width no plough and no-till use in southern Ontario, Canada, and found that both provided modestly higher on-farm benefits than did conventional tillage. The advantage of no-plough and no-till use was even greater with off-site benefits included. The off-site benefits considered were downstream fishing benefits and reduced dredging costs. In addition, Kelly et al. (1996) find that strict no-till produces higher returns than conventional tillage and reduces the environmental hazard index. The index takes into account soil erosion risk, phosphorus and nitrogen losses, and potential pesticide contamination.

Conservation agriculture is more profitable when compared with conventional agriculture in steep-sloping, high rainfall tropical regions than in flatter temperate areas, since the former would be subject to a higher risk of erosion under conventional agriculture.

In mechanized conservation agriculture, many CA analyses suggest that CA reduces machinery costs. Zero or minimum tillage means that farmers can use a smaller tractor and make fewer passes over the field. This also results in lower fuel and repair costs.

Australian research (Kirby et al., 1996) shows that CA results in more stable yields than conventional agriculture, while work in Canada indicates that net returns were higher under CA than conventional practices in bad years (FAO, 2001a). More certain are the impacts of CA on cropping intensity. With reduced preparation time, the cropping cycle is shorter, allowing more crops in a given period and even double cropping where it was not possible previously. Where this benefit is attributable to CA, more efficient utilization of the fixed land resource results in higher annual net returns per hectare.

In Paraguay, yields under conventional agriculture declined 5-15% over a period of 10 years, while yields from conservation agriculture increased 5-20% over the same period (Sorrenson, 1997). Sorrenson (1997) compared the financial profitability of CA on medium and large-sized farms over 10 years. He found that by the tenth year net farm income had risen on CA farms from under US\$10,000 to over US\$30,000, while on conventional tillage farms net farm income fell and even turned negative. There was also less soil erosion, improvements in soil structure, an increase in organic matter content, and higher crop yields and cropping intensities. In addition, there was reduced time between harvesting and sowing crops, thus allowing more crops to be sown over a 12-month period. Furthermore, there were decreased tractor hours (hence fuel costs and repair and maintenance costs), farm labour, machinery costs, and use of

fertilizers, insecticides, fungicides and herbicides. There were also cost savings from reduced contour terracing and replanting of crops after heavy rains. Overall, there were lower risks on a whole-farm basis because of higher and more stable yields and diversification into other cash crops.

To consider the attractiveness of CA in relation to alternative conservation practices to a smallholder, the FAO (2001a) compiled a database of over 130 different analyses of individual soil and water conservation technologies in Africa and Latin America. The results indicated that conservation agriculture tends to show higher net returns at the farm level than do conventional tillage techniques.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) compared yields from farmers practicing CA (planting pits) with farmers using conventional techniques and found that CA yields were 80% higher than those from conventional agriculture. When micro-dosed nitrogen fertilizer was included in the CA practices, yields were 340% higher than conventional farming. CA outperformed conventional practices every year except one year during the 30 years of comparisons (Wagstaff and Harty, 2010).

7. Adoption of Conservation Agriculture

The adoption process of CA can be divided into four theoretical phases. The first phase entails improvement of tillage techniques. During this phase, no increase in farm output is foreseen. But decreases in labour, time, and draft power would occur. An increase in agro-chemical use, especially to control weeds, might be required. The second phase involves improvement of soil conditions and fertility. In this stage there are decreases in draft animal and motorized power (reduction of production costs), increases in yields, and consequently in net farm income. The third phase entails diversification of the cropping pattern, increased and more stable yields, and increased net farm income and soil fertility. In the fourth stage the integrated farming system is functioning smoothly, and stability in production and productivity becomes evident. In this final stage the full technical and economic advantages of conservation agriculture can be appreciated by the farmer (FAO, 2015).

There are four requirements for the adoption of CA practices. First, it must bring the farmer a visible and immediate economic or technical benefit. Secondly, the benefit must be substantial enough to convince the farmers to change their ongoing practices. Third, for the technology to be disseminated, the costs should be affordable to the farmer; and lastly, the introduction of CA should be followed by an extension service for a long period of time (FAO, 2005).

Adoption of conservation agriculture at the farm level is associated with lower labour and farm-power inputs, more stable yields and improved soil nutrient exchange capacity (FAO, 2001a). However, the phenomenon of lower labour inputs is mainly associated with more mechanized forms of CA. Conservation agriculture is practiced on about 57

million hectares, or on about 3% of the arable land worldwide (FAO, 2001a).

Farmers who switch over to some new techniques such as conservation agriculture do so for a variety of reasons. First, they may do so because they have detected a more efficient and profitable way to produce. They may also perceive a problem and in seeking solutions arrive at a new practice, such as CA. The problems stimulating the possible change to CA are typically soil degradation, soil erosion or declining crop yields due to decreasing soil fertility. Some farmers have adopted CA because they found that immediate yields or profits were attractive. In this situation, a clear financial incentive has induced the change in behaviour (FAO, 2001a).

Regardless of the motivating factor or the model of adoption assumed, farmers consider only those aspects of their operation that are relevant from a private perspective. This process typically involves only on-farm considerations. However, it could extend to impacts on neighbours and future generations if social relations and stewardship considerations receive high personal priority. In the private perspective, farming households make technology choices about the use of their soil resources under the constraints imposed by their socio-economic attributes and on-farm resources, as well as higher level factors at the local to global scales. For example, if the farmer is lacking adequate tenure and access to credit, he cannot invest in CA if this requires a large capital outlay (FAO, 2001a).

Information about new technologies and financial conditions is a precursor to changes in farm practices and acquiring it does not usually involve a large financial outlay. Government credit and extension policies play an important role here.

In contrast to the more direct working of agriculture sector policies and financial incentives, some social and institutional factors have a more indirect influence. Nonetheless, all these factors affect the net returns, risks and other pecuniary elements that drive the decision-making process.

Farmers' perceptions are also important in the decision making process. Changing policies and financial incentives or declining natural resource quality signal to the farmer that the current pattern of use of household resources may no longer be desirable. There is controversy over the extent to which farmers perceive the progressive deterioration in their natural resource base. However, there is now sufficient evidence that smallholders are often aware of soil degradation, although other factors affecting production may mask this at times (FAO, 2001a).

One of the success stories of CA adoption has been in Latin America. Large scale mechanized farming is common in many parts of Latin America and farmers have adopted CA on large portions of this cultivated area. (FAO, 2001a).

Farmer characteristics that determine the rate and intensity of CA technology adoption include awareness, education, experience, income, and farmers' goals. Gould et al. (1989)

emphasize awareness to soil erosion or other soil problems facing farmers as an obvious pre-requisite to the adoption of CA technology. Indeed, farmer awareness or perception of soil problems is frequently found to positively correlate with CA adoption (Stonehouse, 1991). Education, be it specific or general, generally correlates positively with the adoption of CA practices, notwithstanding some findings of insignificance or even negative correlation (Rahm and Huffman, 1984; Marra and Ssali, 1990; Warriner and Moul, 1992). Based on a study of conservation tillage adoption in Wisconsin, Gould et al. (1989) showed that older and more experienced farmers were more likely than their younger colleagues to recognize soil problems. However, they were less likely than their younger colleagues to address these problems once recognized. Several studies have found that income correlates positively with the adoption of soil erosion control practices (Okoye, 1998; Wandel and Smithers, 2000). Finally, a good fit between CA and the farmer's production objectives or goals encourages adoption.

Farm characteristics that determine CA adoption include farm size, soil erosion, land productivity, and land tenure. Many studies have found that farm size correlates positively with CA adoption (e.g. Westra and Olson, 1997). However, other studies have shown no significant relationship between farm size and adoption (Agbamu, 1995; Uri, 1999), or even a negative correlation (Shortle and Miranowski, 1986). Hence, the overall impact of farm size on adoption is case- or site-specific. Some studies have found that the presence of soil erosion and other soil problems on the farm correlates positively with conservation tillage adoption (Stonehouse, 1991). However, farmer awareness of and the concern for soil problems is probably the more critical factor affecting adoption. Another important farm characteristic is underlying land productivity. In the case of no-till and mulch tillage, Uri (1997) shows that in the United States adoption is more likely on farms with low rather than high levels of fertility.

In the smallholder sector in sub-Saharan Africa, despite nearly two decades of development and promotion by the national extension program and numerous other projects, adoption of CA has been extremely low compared to other countries such as those in South America, North America and Europe. The low adoption has been due to a number of constraints which include the following: a low degree of mechanization within the smallholder farming 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 low availability of labour (Twomlow et al., 2006).

Tsegaye et al. (2008) assess the impacts of conservation agriculture on land and labour productivity in Ethiopia. Their study analyzes the different components of CA and finds that the initial decision to adopt CA is influenced by regional location, family size, access to extension, and formal education. They also find a positive relationship

between land productivity and the use of CA components such as herbicide application.

8. Potential of CA on smallholder farms

Conservation agriculture is a technology that has potential appeal for smallholders, not only in Latin America, but also in other parts of the developing world. However, adopting CA on a small, possibly non-mechanized farm involves some different considerations when compared to a large mechanized farm. For example, as smallholders use few purchased inputs, discussions on large increases in herbicide costs may not be relevant. In addition, even if smallholders accept the need for herbicides, they may be unable to finance their purchase. Furthermore, few farmers use significant amounts of fertilizer, so that the debate over the impact of CA on fertilizer use is largely irrelevant. Ultimately, the availability of credit to assist with CA's increased need for purchased inputs plays an important role. The majority of smallholders worldwide do land preparation and weeding manually, and adopting CA has its greatest impact on the labour used in these activities (FAO, 2001a).

In a comparative analysis of traditional bush fallow systems with no-till and alley cropping in Nigeria, labour savings under the no-till technology were substantial (Ehui et al., 1990). In studies of smallholders in Latin America, net farm income and returns to labour were much higher under CA than conventional practice. In judging the attractiveness of CA in smallholder systems in Africa, Latin America and elsewhere, labour savings are a key factor. A further point related to labour is that as the labour savings come at both the land preparation and weeding stages (assuming herbicide use), there are liable to be implications for the gender division of labour. In most smallholder systems in Africa, male household members are responsible for land preparation (with a contribution to sowing) while female household members are responsible for weeding. Herbicide use for weed control may require some adjustment in these responsibilities as male household members usually handle pesticides.

Certain conditions can enhance the relative financial attractiveness of CA among smallholder farmers. One of these conditions is land pressure, which tends to increase the financial attractiveness of CA relative to bush fallowing. An additional consideration is land quality. Studies of the net returns from mulching, an important component in smallholder CA, suggest that the benefits of this practice increase with the quality of cropland (Lamers et al., 1998). Another condition of the financial attractiveness of CA is the availability of credit. Successful instances of CA adoption in Latin America have demonstrated the importance of credit as an important enabling factor. This is because of the need to finance specialized planting equipment and herbicides.

A number of studies have sought to identify barriers to adoption beyond the obvious divergence between on-farm costs and wider social benefits under CA (e.g. Smit and Smithers, 1992; Pierce, 1996; Cary and Wilkenson, 1997). These barriers include large investment costs which may discourage adoption; the perceived risk of adopting CA; and long gestation periods for the benefits of CA to materialize.

The potential CA adopter may be confronted with a number of constraints such as purchasing power shortages, access to credit and information, and poor communication links with product and input markets. In this regard, the availability of inputs in the quantity and at the time required may prove to be important considerations in the adoption process. Claims for the potential of CA in Africa are based on widespread adoption in the Americas, where the effects of tillage were replaced by heavy dependence on herbicides and fertilizers (Giller et al., 2009). In Africa, available evidence suggests virtually no uptake of CA in most sub-Saharan African countries, with only small groups of adopters in South Africa, Ghana, Zambia and Zimbabwe. The inference is that there is an urgent need for critical assessment under which ecological and socio-economic conditions are best suited for smallholder farming. Giller et al. (2009) suggest that critical constraints to adoption appear to be competing uses for crop residues, increased labour demand for weeding, and lack of access to, and use of external inputs.

9. Conclusion

This paper has presented some positive aspects of conservation agriculture. Conservation agriculture has emerged as an alternative to conventional agriculture. The rationale or case for CA is its potential ability to reduce soil degradation through several practices that minimize the alteration of soil composition and structure. It specifically purports to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil, and reduce crop production, productivity and sustainability. CA also increases farm financial profitability and food security and enhances environmental integrity.

Potential economic benefits associated with CA include a reduction in on-farm costs and an increase in yields and long-term yield stability. Ecosystem benefits of CA include stabilization of soils and protection from erosion, reduced siltation of water bodies, recharge of aquifers, and more regular river flows. CA also mitigates climate change by carbon sequestration in soils and reduced burning of crop residues. Sequestration and reduced burning of residues result in reduced emissions of CO₂, the major greenhouse gas, with the consequent decline in global warming, leading climate change mitigation.

Farmer characteristics that determine the rate and intensity of adoption of CA technology include awareness, education, experience, income and farmers' objectives. Farm characteristics that determine that determine CA adoption include farm size, soil erosion, land productivity and land tenure. Constraints to CA adoption in sub-Saharan Africa include a low degree of mechanization within the smallholder farming 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 labour shortages.

There appears to be considerable potential for adoption of CA under smallholder farming systems of sub-Saharan Africa. However, the only feasible way to tap that potential appears to rest with the establishment and implementation of appropriate policy initiatives that address ecological, financial and socio-economic constraints facing the smallholder farming sector.

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