ADAPTABILITY AND ADOPTABILITY OF SOIL AND WATER CONSERVATION PRACTICES TO DERIVE BEST-BET OPTIONS FOR SMALLHOLDER FARMERS IN KWAZULU-NATAL

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ACRONYMS

CA – Conservation Agriculture

FAO – Food and Agricultural Organisation

NGO – Non Governmental Organisation

IRWH – Infield Rainwater Harvesting

RWH – Rain Water Harvesting

SSA – Sub Saharan Africa

SWC – Soil Water Conservation

1. INTRODUCTION

Soil nutrient depletion is considered the chief biophysical factor limiting smallholder production in Africa (Drechsel *et al.*, 2004). Soil erosion is one of the major causes of nutrient depletion, as it removes nutrients and organic matter and, as a result, crop yields and water productivity decrease. A decline in soil organic matter reduces soil particle aggregation, which, in turn, reduces the soil water holding capacity, thus increasing the soil susceptibility to erosion. Land degradation hampers the capacity of smallholder farmers and communities to deal with the solutions needed to reverse the situation (Shiferaw *et al.,* 2009). The need for addressing human nutritional necessities remains a challenge, due to the increasing vulnerability of livelihoods caused by the degradation of resources.

The demand for food is increasing, due to the increasing population and the demands for food security and more nutritious food need to be met (Hobbs, 2007). Crop production in the next decade will have to be undertaken on less land, through the efficient use of natural resources, such as water, while having a minimal impact on the environment (Hobbs *et al.,* 2008). Green water is the main source of 80% of the world's cultivated land and yet only about 15% of the actual rainfall is used productively for crop growth (Rost *et al.,* 2008). Green water is defined as water that is located in the soil and dryland agriculture mainly depends on it (Rost *et al.,* 2008). This poses a challenge, as adequate water supplies are a major constraint for subsistence crop production (Li, 2000), especially in semi-arid regions, where rainfall is erratic and soil erosion is apparent (Bekele and Drake, 2003).

Research has shown that it is possible to restore and preserve the environment, while simultaneously boosting agricultural production with the use of Conservation Agriculture (CA) farming technologies (Li *et al.,* 2000). CA is based on three principles, which entail minimum disturbance to the soil, permanent soil cover or mulching and diversified crop rotations that aim at rebuilding the soil, optimising crop production inputs, including labour and optimising profits (Dumanski *et al.,* 2006). These principles have led organisations such, as the Food and Agriculture Organisation (FAO), Non- Governmental Organisations (NGOs) and Government institutions, to promote the adoption of CA by commercial and smallholder farmers.

The principles of CA are also inclusive of the principles of insitu Rain Water Harvesting (IRWH) (FAO, 2001). IRWH is also referred to as water conservation and involves the prevention of run-off from a cropped area, by increasing soil water storage (Hatibu and Mahoo, 1999). IRWH is achieved through soil and water conservation (SWC) farming techniques such, as contour farming, ridging, *zai* pits, *fanya juu* and micro-basins. The success of the adoption of each technique varies with location, based on the local socio-economic characteristics of farmers and the bio-physical attributes of the areas concerned. Studies have shown that crop yield under dryland agriculture can be doubled by using rainwater water harvesting techniques (Meyer, 2010).

In Zimbabwe, the adoption of IRWH enabled farmers to practise intercropping, where new crops were introduced and two or more crops could be grown during the same season (Mutekwa and Kusangaya, 2006). There is a need for agricultural production methods, to incorporate SWC techniques to facilitate crop growth, in order to increase water use efficiencies and soil fertility. In a quest to maximise crop production, SWC techniques have been promoted among smallholder farmers. Smallholder farmers, face constraints in production, labour supply and resources, which affect their capacity to adapt to changes (Peret and Stevens, 2003; Giller *et al.*, 2009).

This review will look at the dynamics involved with the adaptation and adoption of SWC practices by smallholder farmers drawing on literature studies mainly in Sub-Saharan Africa (SSA) and across the world. In understanding the dynamics that control the adoption and adaptation of SWC techniques, the review discusses the different SWC techniques, the SWC implements (machinery) used and the diffusion of the techniques, to the smallholder farmer. The review also discusses econometric procedures used in assessing the adoption of the technology, to get the best management practices from the technology, and includes an assessment of the adaptability of the technology. Adaptation is defined by Smit and Wandel (2006) as a process, action or the outcome of change in a system, in order for the system to better cope with, manage or adjust to some changing condition. The adoption of innovation simply refers to the application of improved technologies and the continuation of their use, even after the projects have been terminated. The adoption of innovation often comes after the adaptation of the innovation.

2. SMALLHOLDER FARMING IN SUB SAHARAN AFRICA

According to Livingstone *et al*. (2011), smallholder farming is practised on land that is 2 ha, or less. About 80% of all farmers in SSA are smallholder farmers and they contribute up to 90% of the food production in some countries. Smallholder farming produces mainly staple food for household consumption and only a very little makes it to the market. Smallholder agriculture is highly differentiated by gender, with women making up the large percentage, as they farm mainly for household consumption (Lahiff and Cousins, 2005; Livingstone *et al.,* 2011).

The largest proportion of SSA's undernourished population are concentrated among smallholder farmers, hence it is at the smallholder unit that the intervention should be done, to influence land and water management that will have a positive impact on rural livelihoods (Bassio *et al.,* 2010). Smallholder agriculture is simply too important to be ignored, as it provides employment, human welfare and political stability in SSA (Delgado, 1999).

According to Delgado (1999), structural constraints facing smallholder farmers in Africa entail poor infrastructure and unreliable markets for agricultural inputs and outputs. To increase production, using less additional land and labour, smallholder farmers need to increase their own productivity through greater capital and technology investments (Livingstone *et al.,* 2011). Hence, continued smallholder production growth will require increased investments, in technology intensification.

Studies in eastern and southern Africa by Jayne *et al*. (2003) have found that there is a strong correlation between land access and household income for farms that are below 1 hectare per capita. In rural areas, where the bulk of household income comes from agriculture, the reduction of poverty does not entirely lie with increasing agriculture, but also in the distribution of assets (such as land) (Jayne *et al.,* 2003). Land plays a key role, hence equitable land distribution patterns have been found to generate higher rates of economic growth compared to land in the hands of the few (Jayne *et al.,* 2009). Structural transformation that starts with the creation and mass adoption of new farm technologies that are smallholder-oriented, is considered by most developmental economists to be key in creating a pathway from a subsistence agricultural society, to one that is food secure, economically diverse and prosperous (Jayne *et al.,* 2012).

2.1 The Principles of Conservation Agriculture

Conservation Agriculture (CA) is a dynamic technology which develops and changes with time hence, there is a need for stakeholders to align themselves with the adjustments that may be required to make the adoption thereof successful. There is a need for farmers to know if they are running an increased risk of growing their crops and how the crop yields will be affected by adopting CA. A review undertaken by Andersson and D'souza (2013) revealed that the challenges faced by smallholder farmers, with respect to the adoption of CA practices, were related more to the challenges encountered with the CA practices than the socio-economic state of the farmers. In defining the principles of CA, the three principles of CA are discussed in detail, while also looking at the factors that impede the adoption of these principles.

2.1.1 Mulching

The use of crop residue to cover the soil is called soil mulching. Crop residues can be sourced through various means, varying from cover crops (e.g legumes) grown and cut to specifically provide mulch, or from a previous crop left after harvest. Soil mulching reduces wind and water erosion (Hobbs *et al.,* 2008). Soil mulching has a number of benefits such, as reducing evaporation, moderating the maximum temperatures in the soil surface layers, improving soil water infiltration, increasing soil porosity and increasing soil aggregate stability (Giller e*t al.,* 2012). Soil moisture conservation, increased soil organic matter and reducing erosion are also benefits of soil mulching (Grabowski, 2008).

The increase in the microbial activity through mulching leads to a more stable soil aggregate and better protection of the soil surface layer (Hobbs, 2008). Mulching has been shown to effectively reduce the risk of crop failures in semi-arid regions, due to the better capture and use of rainfall. Studies on minimum tillage practices in the semi-arid and dry sub-humid locations in the eastern and southern Africa have shown an increase in crop yields and water productivity, with little or no mulch present (Giller e*t al.*, 2012). This was attributed to the water harvesting effects of minimum tillage practices and fertilizer use along ripped and sub-soiled planting lines. The use of mulch is a challenge, because farmers cannot retain residue in areas where crop-livestock interaction is strong, as compared to areas like Mozambique and Malawi where the interaction is low (Thiefelder *et al.,* 2012). In areas where crop-livestock interactions are strong, the installation of feedlots and agroforestry systems can increase and maintain the supply of soil mulch (Harrington and Erestein, 2005).

2.1.2 Minimal soil disturbance

According to the Food and Agriculture Organisation (FAO), *"Conservation tillage is a set of practices that leave crop residues on the surface, which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure-forming element in the soil. Nevertheless, conservation tillage practices such, as zero tillage practices, can be transition steps towards Conservation Agriculture."* Soil tillage has been attributed to reduce soil fertility through the oxidation of organic matter from soil turning and to also accelerate soil erosion (Laddha and Totawat, 1997).

The impacts of badly chosen tillage, as illustrated by Hobbs (2010) Figure 2.1, indicate how tillage can lead to low crop yields, pollution and high production costs. The adverse effects of convectional tillage led to the promotion of conservation tillage by the FAO, NGOs and government structures. However, the adoption of conservation tillage in Africa is still low (Mashingaidze *et al.,* 2012). About 110 million hectares of land is under CA worldwide (Derpsch *et al.,* 2010). Africa only makes a contribution of 0.4 % of the total hectarage, with the majority of the land under conservation tillage being under commercial farms in South Africa (Kassam *et al.,* 2009).

The majority of smallholder farmers in SSA still cultivate their land through conventional plough tillage, with areas reportedly under conservation tillage barely exceeding 1 ha per farming household (Kassam *et al.,* 2009).The main challenge posed by conservation tillage for smallholder farmers in Africa is the amount of weeding that is required following planting. According to Laddha and Totawat (1997), zero tillage can severely affect the growth and establishment of plants through increased weed competition and poor physical condition of the soil. The weed intensity on minimal tillage, compared to conventional tillage, is the main limiting factor in the adoption of minimum tillage.

In Southern Africa it was reported that the amount of labour required for hand hoe weeding more than doubled in areas under minimum tillage (Mashingaidze *et al.,* 2012).

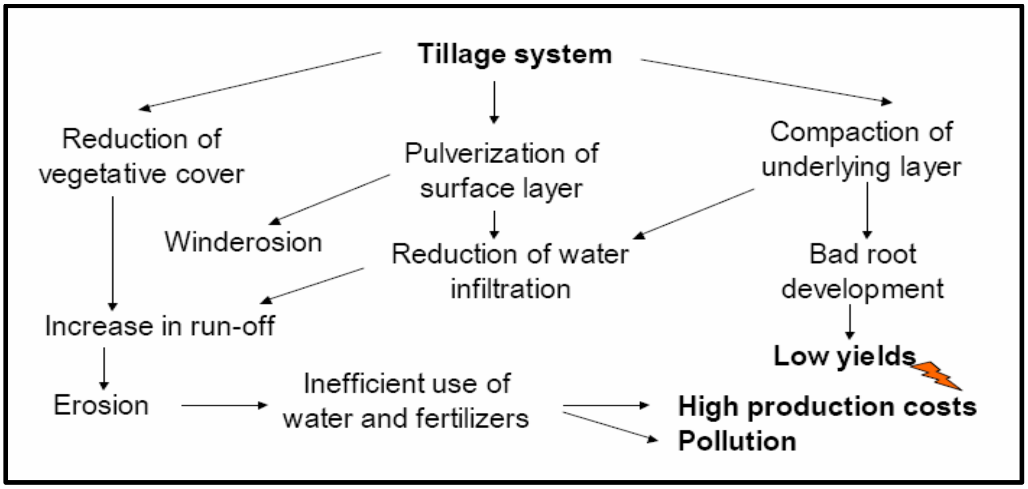

Figure 2.1 The impacts of badly chosen tillage (Hobbs, 2010)

Another impediment to the adoption of no till is the mind-set and perception of the farmers. Reduced but adequate tillage has been found to be highly useful in improving soil physical conditions and crop yields, without adverse effects on the environment (Hobbs, 2008). The main function of soil tillage is to create conditions that are suitable or conducive to plant growth. Innovations have been made for minimal soil disturbance in the form of planting systems like the animal-drawn and two wheel tractor seeding implements that permit adequate seeding into minimally disturbed soils (Johansen *et al.,* 2012).

A study in the Bhilwa region in Western India (Laddha and Totawat, 1997) found that the highest value of bulk density and the lowest value of soil porosity and other physical parameters were found under zero tillage treatment. A significantly low bulk density with high soil porosity was observed under deep tillage. This study also indicated that deep ploughing treatments (disc and chisel) increased the soil volumetric water content surface, subsurface and deeper soil layers at sowing, as well as at harvest time for two consecutive years. This resulted in the tillage treatment showing significantly higher yields of sorghum, green grain seed and sorghum equivalents, when compared to zero tillage for both years. Even though no till has shown great adaptability to all kinds of soils, climates and cropping conditions (Derpsch *et al.*, 2010), the study in India indicates that it is not equally suitable for all agro-ecosystems.

2.1.2 Intercropping

Intercropping refers to the cultivation of two or more crops simultaneously in the same field (van Acker, 2005; Szumigalski and Machado, 2009; van Wolfswinkel, 2010). Intercropping crops do not necessarily have to be planted or harvested at the same time, but should rather be grown at the same time for a great part of their growing season (Lithourgidis *et al.*, 2011). The species that can be used for intercropping vary between annuals (legumes and cereals), perennials (shrubs and trees used mostly in agroforestry) and a mixture of both. Intercropping offers several benefits, including increased yields (Li *et al*., 2001; Zhang and Li, 2002), biodiversity and stability (Latif *et al.,* 1992; McLaughlin and Mineau, 1995; Hole *et al.,* 2005), improved soil fertility (Moreno *et al.,* 2006; Beedy *et al.,* 2010), weed control (Liebman and Dyck, 1993; Olasantan *et al.,* 1994), pest and disease control (Trentbath, 1993; Li *et al.,* 2012), soil cover (Shili-Touzi *et al.*, 2009; Amosse *et al.*, 2012), as well as fodder and manure (Singh *et al.,* 2010).

The challenge faced by farmers, leading them to not adopt intercropping, is the unavailability of seeds and dysfunctional markets for their produce (Snapp *et al.*, 2002; Thiefelder *et al.,* 2012). Another shortcoming is the perceived loss of area for the rotational crop in favour of the main food crop farmed in most subsistence households in Southern Africa (Thiefelder, 2013). There is also a lack of information concerning the benefits of crop rotation, as benefits such as improved soil fertility, breaking the pest and disease cycle and reduced crop failures, are still unknown to some farmers (Thiefelder *et al.,* 2012).

2.2 Soil and Water Conservation and In-Situ Rainwater Harvesting

IRWH has been promoted to solve the problem of water shortages for agricultural production (Li, 2003). Micro-catchment rainwater harvesting has been useful in arid and semi-arid regions where irrigation water is not readily available or expensive to use (Li *et al.,* 2000). Water harvesting structures have improved the standard of living of smallholder farmers, where the harvest of domestic crop production without water would not be feasible (Renner and Fraiser, 1995). In China, the implementation of RWH has been a success as it improved crop production and also solved drinking water problems (Li, 2003). The implementation of IRWH and roof RHW in the Free State Province in South Africa increased the gross returns to the value of produce per home garden by approximately 22% per annum (Viljoen *et al.,* 2012). The increase in the value of produce was attributed to the significance in water supply through RWH techniques. The objective of IRWH conservation technology is to maximise soil water storage by minimising water loss through runoff, deep percolation and evaporation (Ngigi *et al.,* 2006).

This reduces the amount of runoff generated and controls soil erosion thus, reducing the negative side effects of excess runoff. Other agronomic practices under this category include mulching, ridging and micro-catchment systems such as, tied ridges, bunds, contour furrows and bench terraces (Shiferaw *et al.,* 2009). IRWH is one of the cheapest and simplest forms of RWH systems. However, in a semi-arid context, especially on coarsely- textured soils with low soil moisture storage capacity, the prospects of in-situ conservation may offer little or no guarantee against poor rainfall distribution (Ngigi *et al.,* 2006). The benefits of soil moisture conservation are more visible when soil fertility improvement measures are considered and incorporated.

2.3 Overview of the Most Commonly Practiced Infield Rain Water Harvesting Techniques in SSA

In Sub Saharan Africa (SSA), dryland agriculture makes up more than 95% of the farm output (Rockstrom, 2009). In SSA dryland areas, investment in systems that are based on increasing the efficient use of rainfall have been neglected, while support has focused on water provision for crops through the costly development of irrigation schemes (Rockstrom, 2009). In the late 1970s and early 1980s, the potential for IRWH in SSA received great attention, due to widespread droughts that led to crop failures, leaving the livelihoods of people living in communal areas the most vulnerable (Mutekwa and Kusangaya, 2006). There are a number of other SWC techniques used in SSA and, for the purpose of this study, the techniques that are common in Southern Africa are discussed in detail. The most commonly-used RWH technologies in SSA include contour farming, *fanyajuu* terraces, *zai* pit system and micro-basins. Tied ridging is a technique used to promote CA, due to its conservation of rainwater in farmer’s fields (Wiyo *et al.,* 2000).

2.3.1 Tied ridging

The effectiveness of tied ridging in reducing surface runoff and increasing soil water storage has made it a form of CA. Tied ridging involves creating ridges that are 20–30 cm high with a spacing of 75 cm wide. The ties can be prepared either before, during or after planting (Brhane *et al.,* 2005). Tied ridges have been found to be effective and feasible for diverse situations. It has been also effective in increasing soil water storage and reducing surface runoff thus increasing crop yield in countries like Zimbabwe, India and the USA (Brhane *et al.,* 2006), whereas, in certain instances, it has led to waterlogging, excessive nutrient leaching and ridge destruction in wet areas (Wiyo *et al.,* 2000).

2.3.2 Contour farming

Contour (across-slope) cultivation refers to farming along the lines of equal contour (which is the curved line that follows the land surface) (FAO, 1998). The establishment of any crop in contour farming will first require systematic tillage to be applied. Thus, the soil preparation and terracing should be established along the lines of the contours. Contour farming should be implemented in areas with a slope that is not too long, hence it is recommended as an isolated erosion control measure (FAO, 1997). Contour farming can be achieved through the application of mechanical SWC techniques such the *fanya juu* terraces, micro-basins and stone bunds.

2.3.3 *Zai pits*

The *zai* pit technique, seen in Figure 2.2, is used to increase tree and crop production. In, Burkina Faso, the adoption of the *zai* pits led to the rehabilitation of between 200 000 and 300 000 ha of land, which was formerly degraded and abandoned (Meyer, 2010). In the small pit, organic matter and manure are added to the cultivated area, to improve the soil structure (Renner and Frasier, 1995). *Zai* pits can fit about 10–15 seeds of sorghum or millet and are usually dug during the dry season. The sowing is done at the beginning of the rainy season or during the dry season (Sedibe, 2005). The pits are dug in an alternate pattern that are more or less a meter apart, with basins that are 30–50 cm wide and with a depth of 10–20 cm (Renner and Frasier, 2005; Sedibe, 2005).

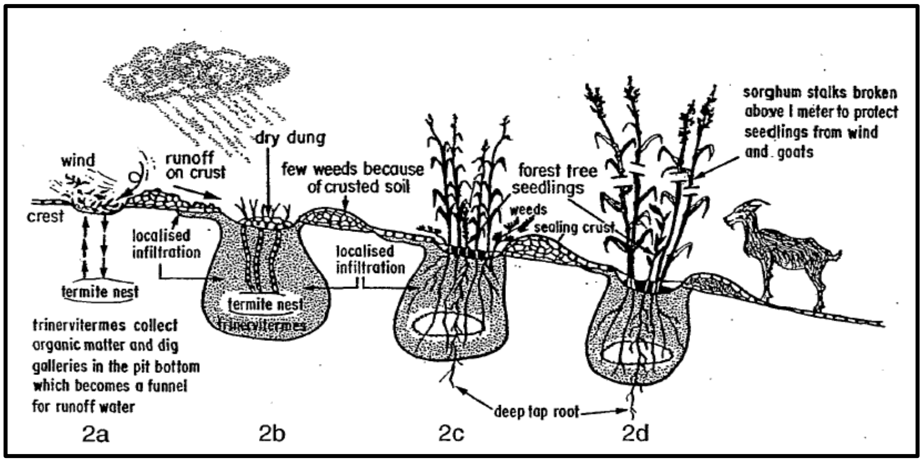

Figure 2.2 Illustration of the *zai* pit technique (Roose *et al.,* 1999)

According to Roose *et al.* (1999), the hours required for hard work on a *zai* system is 300 hours per ha and the transportation of 3000 kg of dry dung is required. Challenges in using the *zai* system are the intensive labour input and manure availability. Another shortcoming of the *zai* system is that it can only reduce the impact of drought for up to three weeks, based on the water holding capacity of the soil, hence the soil profile matters. In the event of excessive rain pit clogging and nutrient leaching has been observed. Optimal conditions for the system has been observed in areas that receive 400–800 mm of rainfall in Burkina Faso (Roose *et al.,* 1999).

2.3.4 *Fanya juu* terraces

Fanya juu terraces are constructed with an embankment that is put in an upslope position. The embankment is formed by the soil being thrown uphill to make a ridge, by digging a drainage channel (FAO, 1993; WOCAT, 2007). *Fanya juu* terraces (seen in Figure 2.3) are usually constructed along the contour to capture rainfall, especially in semi-arid regions. In sub-humid conditions, the terraces are oriented laterally, to discharge excess runoff (WOCAT, 2007). The objective of the *fanya juu* is to improve plant growth, by minimising water and soil loss.

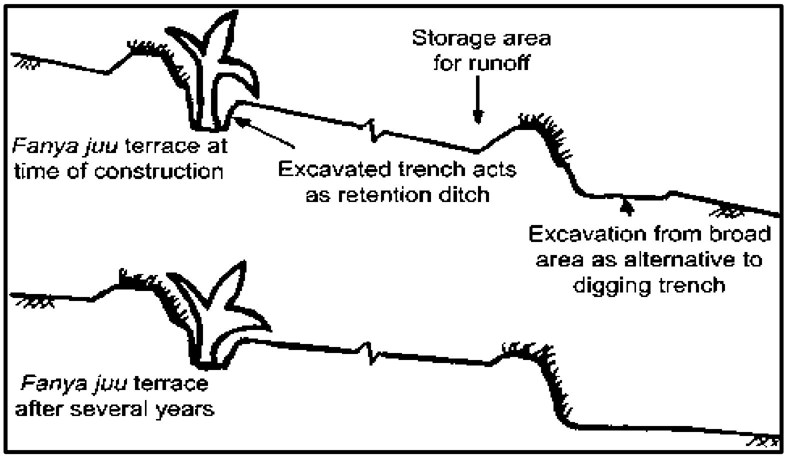

Figure 2.3 *Fanya juu* terraces during construction and after several years (Thomas, 1997)

The design dimensions of the *fanya juu* are 0.6 m deep by 0.6 m wide. The height of the bund is 0.4 m, with a base width of 0.5–1 m, the terraces are constructed 10–20 m apart. As time passes, the soils between the banks evens out to form level benches that result from surface erosion and tillage (Figure 2.3). The construction and maintenance of the *fanya juu* is labour- intensive, thus the amount of labour required increases as the slope becomes steeper, due to the closed spacing of the structures (WOCAT, 2007). To construct the *fanya juu* terracing on a 15% slope by hand would take 90 man-days per hectare (WOCAT, 2007).

2.3.5 Micro-basins

Micro-basins are constructed along the retention ditches for tree planting, and they are roughly 1.0 m long and less than 50 cm deep (Previati *et al.*, 2009). Micro-basins aim to retain water *in situ* or to slow down the runoff water velocity. These structures are used to rehabilitate degraded land by water erosion and increased yields have been reported for crops planted on these basins (Ngigi, 2003). The basins are dug during the dry season, to allow planting at the onset of the rainy season and the precise application of fertilizer and manure (Thiefelder *et al.*, 2012). The disadvantage of micro-basin use is the labour required to construct them.

2.3.7 Stone bunds

Stone bunds are stones installed along the contour lines. The sediment that accumulates behind the semi-permeable stones results in the development of progressive terraces (Vancampenhout *et al.,* 2006). The construction of stone bunds starts by placing large rock fragments along the contour, followed by medium-size rock fragments that have a diameter of 5-10 cm as backfill and the backfill is topped by small rock fragments with a diameter of 2 cm that serve as a filter and also retain sediment (Nyssen *et al.,* 2007). The stone bunds also serve as a barrier to water- induced erosion (Vancampenhout *et al.,* 2006). The benefits of stone bunds include increased soil water status and crop yields (Zougmore *et al.,* 2000). The performance of stone bunds has been optimum under water-limiting conditions, with crop damage reported under wet conditions as a result of waterlogging (Vancampenhout *et al.,* 2006). Other challenges associated with this technique are fertility gradients that often result in a decrease in crop yields, direct crop damage due to sediment accumulation and the presence of rats in the structures (Nyssen *et al.,* 2007). More research on the sustainability of stone bunds is required to address these challenges.

2.4 Mechanization Systems Used in Soil and Water Conservation Farming

In the 1970s, farmers in Parana, Southern Brazil, recognised that continued soil erosion and declining crop yields were forcing them to abandon their land and move into marginal areas (Benites *et al.,* 2002). The design and development of CA machinery for smallholder farmers began in Brazil (Johansen *et al.,* 2012). Machinery plays a critical role in the success of CA. When farming under CA principles such as no till, a special planter is necessary to prepare a narrow seedbed that surrounds the seed planted (Machado and Silva, 2001). Equipment for seeding and planting must be able to deposit the seed into untilled soil with a similar level of accuracy as conventional seed drills, which ideally is covered with a heavy mulch of crop residues. According to Hobbs *et al.* (2008), zero-tillage and CA are bound to fail if suitable equipment is not provided for direct seed drilling into residues at the appropriate depth, for good germination. The use of chemical weed control has shown a significant decrease in labour capacity with CA, which positively affects the adoption of CA.

In southern Africa, the use of the manual hoe for weeding was not adopted under CA, due to the labour intensity required for the weeding (Erenstein *et al.*, 2008). Innovations have been made to animal-drawn and two-wheel tractor seeding implements that carry out adequate seeding and minimise disturbed soils (Thiefeider *et al.*, 2012). These innovations were meant to introduce CA for smallholder farmers, to allow them to plant with minimum disturbance to the soil. In southern Africa, three different manual CA planting systems are being used and these include the dibble stick, planting basins and jab planters. Other systems include animal traction systems and two-wheel tractors (Thiefeider *et al.*, 2012). The dibble stick method (Figure 2.4b) involves using a pointed stick that opens a small hole for cow dung, if the operator wishes to incorporate the fertilizer during planting. The dibble stick also facilitates weed control management (Friedrick *et al.*, 2009). This method has been widely adopted in Malawi because it follows traditional planting methods such as, seed planting on ridges.

The disadvantage in using the dibble stick is the difficulty in planting through thick mulch. In southern Africa, a form of CA that involves digging planting basins using hand hoes is mainly targeted at resource constrained households and has been promoted (Nyamangara *et al.*, 2013). The hand hoes (Figure 2.4f) are used to prepare basins that are large enough to accommodate the seed and fertilizer and they remain partially covered in order to collect runoff water at the beginning of the rainy season. The preparation has to be carried out during the dry season, enabling the farmers to plant early, thus the concentration of runoff water into the basins would increase the farmers' yield potential (Nyamangara *et al.*, 2013).

The Jab planter is composed of two compartments that are mounted on a frame with two tips. One compartment is for the fertilizer and the other is for the seed (Johansen *et al.*, 2012). The disadvantage of using the jab planter is the clogging of the tips on soil that is very sticky (Thiefeider *et al.*, 2012). The adoption of jab planters as a tool for direct seeding by smallholder farmers has been low; this difficulty has been attributed to the lack of proper training of farmers on how to use them (Akpoko, 2007). However, the adoption of the *martraca* jab planter (Figure 2.4a) has been widespread in Latin America and has created an interest in smallholder farmers in SSA (Friedrich and Kienzle, 2007). Weed management under CA remains partially unchanged, as cutters and slashes are used for mechanical surface weed management; however, the sprayer

(Figure 2.4d) remains the main tool for herbicide application in weed management (Johansen e*t al.*, 2012).

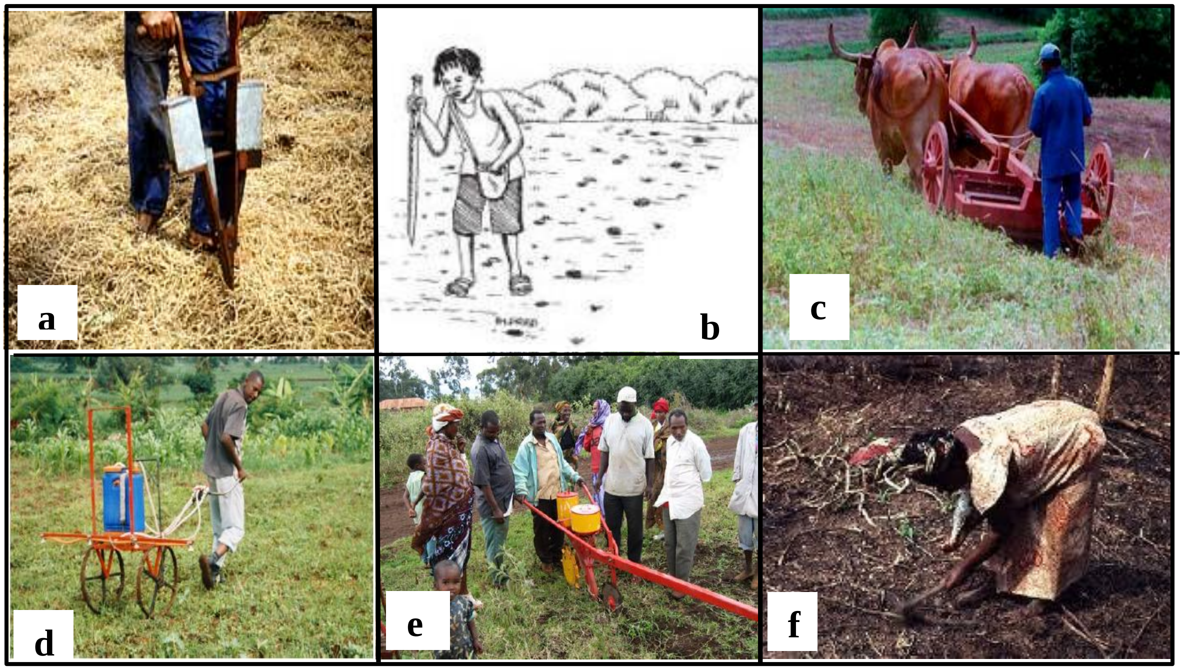

Figure 2.4 (a) a Martraca Jab planter for direct manual planting (FAO, 1993); (b) a dibble stick planter (infonet-biovision, 2011);(c) a knife roller (Sims *et al.*, 2012);(d) a manually-pulled sprayer for herbicides and pesticides application (Sims *et al.*, 2011);(e) an animal traction no till planter (Friendric*et al.*, 2012);(f) a hand hoe used to sow rice in the forest region of Southern Cote d'Ivoire (http://ipmworld.umn.edu,2013).

Weed management under CA does not aim at the complete elimination of weeds, but rather controls the weeds in a way that does not facilitate their multiplication and does not interfere with crop growth (Friedrick *et al.*, 2009). The animal traction direct planter (Figure 2.4e) includes components such as a coulter that cuts through mulch, a seed/fertilizer hopper, a ripper tine that opens a small rip line and a drive wheel that activates fertilizer and seed release, while simultaneously covering the seed (Johansen *et al.*, 2012). The animal traction direct planter has different seed plates for different crops, but has the shortcoming of not having plates for some crops. Another disadvantage of the planter is the price of the implement, which ranges between US$500 to US$600. The management of residue and crop cover plays a vital role in land preparation for seeding. The aim is to increase organic matter through residue cover that is spread evenly (Johansen *et al.*, 2012).

The rolling of the plant residue has been found to be an effective way of controlling weeds. The knife roller (Figure 2.4c) is a useful tool for residue and crop cover management, because it breaks down and flattens the plants in a manner that does not facilitate subsequent seeding. Leaving of crop residues in the soil facilitates seeding, which may cause weeding challenges (Sims *et al.*, 2012).

2.5 SWC Adaptation and Sustainability

Sustainable agriculture has been defined by Reijntjies *et al.* (1992) as farming that is ecologically sound, socially just and acceptable and economically viable. The main aim of sustainable agriculture is to achieve permanence through the adoption of technologies that maintain soil fertility and concurrently utilise renewable resources that minimise environmental degradation (Shiferaw *et al.*, 2009). A vital strategy for sustainable agriculture is through restoring on-farm biodiversity by employing diversified farming systems that imitate nature (Scherr and McNeely, 2008). SWC techniques promise to offer sustainable agriculture, as they seek to address socio-economic and environmental issues through increased food production, while simultaneously sustaining the environment (Shiferaw *et al.*, 2009). The adaptation of SWC techniques to evolving conditions is essential, as it ensures the sustainability of farming, with minimal impact on the environment.

The adaptation of a SWC technique by a smallholder is dependent on the adaptive capacity of the farmer. The adaptive capacity refers to the ability of the system to adapt, which represents the practical means of coping with change (Burton *et al.*, 2002). The adaptive capacity is influenced by the ability of the system to adapt and this is determined by the socio-economic characteristics of the local conditions (Burton *et al.*, 2002; Smit and Wandel, 2006). According to McDonald and Brown (2000), adaptation can be radical or continuous, thus adaptation emerges from the process of SWC. There are a number of factors that influence a farmer's ability to adapt SWC practices and these include access to finance, managerial ability, resources, institutional environment, access to information and the types of technology method (Smit and Wandel, 2006).
Local adaptive capacity has been found to be reflective of broader conditions at the local level (Smit and Wandel, 2006).

Adaptive capacity varies with location and the determinants of adaptive capacity are mainly local. In some places, determinants like the socio-economic conditions and political systems have been found to vary from community to community, among social groups and individuals and over time (Smit and Wandel, 2006).

3. THE ADOPTION OF SOIL AND WATER CONSERVATION PRACTICES BY SMALL HOLDER FARMERS

3.1 The Concept of Diffusion of Innovations

Diffusion can be defined as a process by which an innovation is communicated through certain channels over time among the members of social systems (Rogers, 1995). An innovation is an idea, practice or object that is perceived as new by an individual or other unit of adoption (Rogers, 1995). Diffusion differs from adoption in that adoption studies the behaviour of the individual in relation to the use of an innovation. The relation between diffusion and adoption can be observed when both adoption and diffusion are viewed as a dynamic process over time (Jab, 1998).

According to Pennell (1999), there are three broad conditions that are necessary for an individual farmer to adopt a farming innovation. These three broad conditions include the awareness of the innovation, the perception that the innovation is worthwhile testing and it is feasible. The trial refers to the degree to which the innovation can be experimented with on a limited basis, and the perception towards the innovation (Rogers, 1995). The farmer needs to have the perception that the innovation promotes the farmer's objectives. This will depend on the farmer's observability which refers to the degree to which the results of an innovation are visible to others. The easier it is for an individual to see the results of an innovation, the more likely they are to adopt it (Habron, 2004; Rogers, 1995).

The adoption of a technology is influenced by the attributes of the innovation characteristics such, as cost, complexity and impact (Damanpour and Schneider, 2008). Because the characteristics of SWC techniques such as compatibility, complexity, feasibility and trialability (among other factors) vary with the local socio-economic characteristics of the farmer and environmental benefits, investment in adaptive research is needed to tailor the adoption of these techniques to local conditions (Erenstein *et al*., 2008). Pannell *et al*. (2006) divided the characteristics of technology that lead to its adoption or non-adoption into two categories. These categories were based on the relative advantage of the technology that leads to two categories, its adoption or non-adoption. The categories were based on the relative advantage and the trialability of the technology. According to Rogers (2003), the relative advantage of an innovation refers to the perception of the innovation being better than the practice it supersedes. The relative advantage determines the ultimate level of adoption of most innovations in the long run and depends on the socio-economic characteristics of the farmer and environmental factors of the innovation (Panell *et al.*, 2006). The factors that affect the relative advantage of the innovation include its compatibility, cost, complexity and profitability (Pannell *et al.*, 2006). The compatibility of an innovation refers to the ease with which an innovation can be adapted to fit the resources, existing beliefs and values of the farmers (Panell *et al.*, 2006). A highly compatible innovation will be adopted more easily than an innovation with a low compatibility.

The profitability of an innovation refers to the yield after the adoption of an innovation, for example, rising fuel costs and labour requirements led to an increase in the adoption of conservation tillage by commercial farmers in South Africa (Johansen *et al.*, 2012). The ease or difficulty in the understanding of the innovation will depend on the complexity of the innovation, as a more complex innovation will be adopted more slowly than a readily understood one (Rogers, 1995). The cost of a technology is expected to negatively affect the adoption of that technology, thus, a less expensive technology is more likely to be adopted than a more expensive one (Damanpour and Schneider, 2008). The adoption of an innovation can at times add to the complexity of that innovation, for example, if a farmer adopts crop rotations considering a suite of crop types he/she may encounter managerial complexity, if each crop has its own requirements for agronomy and storage (Damanpour and Schneider, 2008).

The second category is the trialability of the technology, which refers to the move from the non-adoption to the adoption of the innovation. Technology complexity is related to the trialability of the technology, which also refers to the degree to which a certain area of technology can be experimented on. The factors that affect the trialability of an innovation include the acceptability, divisibility, observability, complexity and cost of the innovation. The divisibility of an innovation relates to the use of the subcomponent of the innovation package. This can also refer to the use of the innovation on a smallholder farmer (Cornish, 1998). The divisibility of an innovation is reduced, by the high fixed costs of an innovation, for example, innovation that requires the purchase of implements to adopt, have a low divisibility. Observability refers to the degree to which the results of the innovation are visible to others (Rogers, 1995). The observability of an innovation is perceived to positively relate to its adoption. The acceptability of an innovation refers to the adoption prospect of the innovation when still in the inception stage (Chao and Skibniewski, 1995). The acceptability of a new innovation is seen when the technology is compared to another technology used for the same purpose (Chao and Skibniewski, 1995). The characteristics of different SWC techniques are classified in Table 3.1, based on the relative advantage and the trialability of the innovation.

Table 3.1 Characterizing Soil and Water Conservation (SWC) techniques based on literature

Technology characteristics	**Crop rotations**	**Zero- tillage**	**Mulching**	**Tied ridging**	**Contour farming**
1. Complexity	Baldwin (2006)	Knowler and Bradshaw (2006)	Erenstein (2003)	(Brhane *et al,* (2006)	Garrity (1999)
High complexity		√	√		
Moderate complex	√			√	√
Notcomplex					
2. Divisibility	Baldwin (2006)	Hatibu and Maho(1999)	Harrington and Erestein (2005)	Tesfahuneg and Wortmann (2008)	Kuypers *et al*. (2005)
Highly divisible					
Moderately divisible	√		√	√	√
Not divisible		√			
3. Cost	Mashingaidze, (2013)	Giller *et al.* (2009)	Hobbs *et al.*(2008)	Tesfahunegn and Wortmann (2008)	Hatibu and Maho (1999)
Expensive	√	√			√
Moderately expensive					
Not expensive			√	√	
4. Compatibility	Schlegel *et al.* (2002)	Mashingaidze (2013)	Erenstein (2003)	Tesfahunegn and Wortmann (2008)	Kuypers *et al*. (2005)
Highly compatible					√
Moderately compatible	√		√	√	
Not compatible		√			

…Table 3.1 continued

5. Profitability	Mashingaidze, (2013)	Lotter *et al.* (2009)	Harrington and Erestein (2005)	Brhane *et al.* (2006); Pale *et al.* (2009)	Kassie *et al.*(2011)
Highly profitable		√		√	√
Moderately profitable					
Not profitable	√		√		
6. Acceptability	Thiefelder (2013)	Dumanski *et al.* (2006)	Mashingaidze (2013)	Brhane *et al.*(2006)	Kassie *et al.* (2011)
Highly acceptable			√	√	
Moderately acceptable	√	√			√
Not acceptable					
7. trialability	Schlegel *et al.* (2002)	Knowler and Bradshaw (2006)	Hobbs *et al.*(2008)	Brhane*et al.*(2006)	Garrity (1999)
High trialability	√	√	√		
Moderate trialability				√	√
Low trialability					
8. Observability	Baldwin (2006)	Mashingaidze *et al.* (2012)	Hobbs *et al.*(2008)	Chiputwa *et al.* (2011)	FAO (1997)
High observability		√	√	√	
Moderate observability	√				√
Low observability					

NB: Characterisation is based on the authors as quoted in table 3.1.

3.3 Factors that Affect the Adoption of SWC with Focus on CA by Smallholder Farmers

There are a number of factors that affect an individual's decision to adopt or not to adopt an innovation. This factors include the social, economic, physical and technical conditions of the farmers (Johannes *et al.*, 2010). The investigation of farmers adoption behaviour by social scientists has accumulated considerable evidence supporting the fact that demographic variables, information sources, characteristics of the technology, awareness, farmers knowledge, group influence and the farmers perception on the innovation have an impact on the behaviour of the farmer in adoption (Johannes *et al.*, 2010). The socio-economic conditions of the farmer play a leading role in the farmer’s decision to adopt an innovation (Castano *et al.*, 2002; Bekele and Drake, 2003; Bewket, 2006; de Graaf *et al.*, 2008; Kabambaa and Muimba-Kankolongo 2009; Johannes *et al.*, 2010; Greiner and Gregg, 2011). Some of the issues preventing adoption include political interference in land resettlement, unreliable land tenure systems and the lack of effective technology development and dissemination approaches (Ficarelli *et al.*, 2003).

Access to capital for attaining implements, such as planters, sprayer, rippers, fertilizers, herbicides and labour, has been attributed as one of the key limitations to the adoption of CA in southern Africa (Anderson and D’Souza, 2013). The adoption of CA is also affected by governmental policies and the vagaries of nature. Institutional factors and NGOs also play a role in the adoption of SWC technologies, as they facilitate the exposure of SWC, mainly in Africa (Twomlow and Mazvimavi, 2009).

Jara-Rojas *et al.* (2012) gave a summary of the variables that positively or negatively influence the adoption of conservation practices, based on studies conducted in different locations. The variables that were found to have a positive influence on the farmer’s decision to adopt a conservation practice includes education, farm size, the perception of erosion, the provision of extension services, training, age, access to labour, profitability perception and the number of animals (Jara-Rojas *et al.*, 2012). These findings are consistent with the studies that have been done on the factors that impact the adoption of SWC by smallholder farmers (Bekele and Drake, 2003; Sedibe, 2004). Even though the factors that hinder the adoption of SWC techniques have been researched, the implementation of these concepts in practice is still a challenge faced by extension practitioners and researchers (Ficarelli *et al.*, 2011).

3.4 Evaluating the Adoption of Soil and Water Conservation (SWC) Practices

Empirical methods are commonly used in studies on the adoption of agricultural technologies. These studies generally divide the population into adopters and non-adopters (Maddala, 1992). The procedure commonly used to assess the rate of adoption is the use of the logistic curve, which captures the historical trend of adoption over a given time (Mussei *et al.*, 2001). Econometric procedures are required to capture the rate and process of adoption (Mussei *et al.*, 2001). There are two types of models that can be used to measure binary response behaviour and these include the Logit Model, and the Probit Model (Sheikh *et al.,* 2003). A review on the farmers adoption of CA by Knowler and Bradshaw (2006) showed that dummy-dependent variable regression models like the Logit and Probit models are used to analyse the factors influencing the adoption of CA by farmers. In these models, the explained variable is a dummy variable that can take two or more values (Maddala, 1990). The binary variable describing a choice is the dependent variable, rather than an independent variable (Hill *et al.,* 2008). The variables are usually acquired through questionnaires and the questionnaires used should be designed in such a way that they reflect the theoretical model outlined or to be used. In studies involving the adoption of technologies, the model takes on a binary response, where the value of the dependent variable (y_t), can take on only two variables, namely, 0 and 1 (Davidson and MacKinnon, 2004).

The binary response model is also thought of as modelling conditional expectation (Davidson and MacKinnon, 2004). According to Knowler and Bradshaw (2006), the assigning of 0 or 1 to express the adoption and non-adoption in a regression analysis offers more insight than mere correlation. The Logit Model is preferred because it produces explicit class probability, rather than just classification (Sheikh *et al.,* 2003). According to Maiga (2005), previous studies on technology adoption, using the Logit Model, have shown a number of shortcomings that include the failure to distinguish between long- and short-term investment types, failure to use alternative models and to also take into account community pressure. The Probit Model produces similar results to the Logit Model, hence the choice in using either the Probit or Logit Model is a matter of computational convenience (Maddala, 1992; Bekele and Drake, 2003;). The Probit and Logit Models will be discussed in detail, as the models used to study the adoption of SWC technologies.

3.4.1 The Probit Model

The Probit function is related to the standard normal probability distribution. According to, Griffiths *et al.* (1993), the Probit Model is a non-linear statistical model that achieves the objective of relating the choice probability (Pi) to the explanatory factors in such a way that the probability remains in the [0, 1] interval. The Probit Model equation (Maddala, 1992) is written as:

$$P_i = F(I_i) = P[z \leq I_i] = \int_{-\infty}^{Ii} (2\pi)^{-1/2} e\text{-}^{z2/2} dz \qquad (3.1)$$

To develop a Probit Model, the utility index (I_i) for the ($_i$th) individual must first be defined (Maddala, 1992) as:

$$I_1 = \beta_1 + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} \qquad (3.2)$$

By using a vector ($\boldsymbol{\beta}$) notation to let

$\beta = (\beta_1, \beta_2, \ldots, \beta_k)'$ and $x_i' = (1\ x_{i2} \ldots x_{ik})$, the utility index becomes;

$$I_i = x_i'\boldsymbol{\beta} \qquad (3.3)$$

Where x_i is the value of the explanatory variables, when x_i changes the index I_i varies under the real number line. When the value of I_i increases, P_i increases as well. Hence, the larger the value of I_i, the greater the utility individual I_i receives from choosing the option $Y_i = 1$. The index can be:

$$I_i = \beta_1 + \beta_2 x_i$$

$$P_i = F(I_i) = F(\beta_1 + \beta_2 x_{i2} + \ldots + \beta_k x_{ik}) = F(x_i'\boldsymbol{\beta}) \qquad (3.4)$$

Where $F(I_i)$ is the cumulative distribution function of the standard normal N (0, 1) random variable evaluated at $I_{i,}$ the cumulative distribution function is given by,

$$P_i = F(I_i) = P[z \leq I_i] = \int_{-\infty}^{Ii} (2\pi)^{-1/2} e\text{-}z^2/2dz \qquad (3.5)$$

3.4.2 The Logit Model

The Logit Model is a popular alternative to the Probit Model. The Logit Model differs from the Probit Model in the cumulative distribution function that is used to define the choice probabilities; this makes the Logit Model easier to work with (Griffiths *et al.,* 1993).

The Model equation (Maddala, 1992) is written as:

$$P_i = F(x_i'\boldsymbol{\beta}) = F(I_i) \qquad (3.6)$$

Where F (˙) is the cumulative distribution of a logistic random variable and given by

$P_i = F(x_i'\boldsymbol{\beta})$

$$= \frac{1}{1+e^{-x_i'\beta}} \tag{3.7}$$

The advantage of using the Logit Model is that it can be used without any change even, with unequal sampling (Maddala, 1992). The coefficients of the explanatory variables are also not affected by the unequal sampling. The Probit and Logit Models can be extended to a multinomial Probit/Logit Model when the alternatives are more than two and are not ordered in any way (Griffiths *et al.*, 1993). A multinomial Logit Model was used in studying the adoption of SWC techniques by Bekele and Drake (2003) (see Table 7.1 in the Appendix), because it made it possible to study the factors influencing the farmer's adoption of SWC practices, based on the context of individually-specific data based on multiple choices.

A disadvantage of using the multinomial logit model is the independence from the irrelevant alternatives (IIA) property. This means that no provision is made for complementarities among the choices (Hausman and McFadden, 1998). The Hausman type test and the Wald test can be used to test the IIA assumption in the multinomial Logit Model. The Logit Model has been widely used in research studies (Table 7.1 Appendix) to understand the adoption of SWC techniques. In most of the studies, as indicated in Table 7.1 in the Appendix, surveys were conducted to collect data from the smallholder farmers in the form of questionnaires and participatory appraisal methods. The model gives results that will assist in determining the factors that control the adoption of the SWC techniques and will then give the best bet management practices.

3.5 Measurement of Product Adaptability

The adaptability of a product refers to the ability of the created product to be adapted by users to achieve various functions or to enhance its performance (Li *et al.,* 2008). Katayama and Bennet (1999) defined adaptability in a company's production system as the inherent ability to adjust the cost performance according to demand. The adapted product has to satisfy the changed requirement. Products with high adaptability will hold a high marketing advantage through user benefits and environmental friendliness (Cheng *et al.*, 2011). The adaptability of the product can be achieved by modifying the existing product architecture. This may entail replacing the existing product components with new ones, the addition of new components or the reconfiguring of existing components (Cheng *et al.*, 2011). Adaptability can be realised through a number of different organisational and technological solutions (Katayama and Bennet, 1999; Subramaman, 1999). The adaptability of a product can therefore be measured in various ways and, for the purpose of this research, the method used by Chenge *et al.* (2011) will be discussed. Cheng *et al.* (2011) measured two types of product adaptability, namely, essential adaptability and behavioural adaptability. Essential adaptability refers to the ability to realise adaptation from the product architecture and is determined by the individual components that make up the product and its functional integrity. Essential adaptability reflects the cost needed by the transformation of a product from meeting existing requirements to new and anticipant ones (Cheng *et al.*, 2011). Behavioral adaptability refers to the final results achieved by the adaptation process. The degree of customer satisfaction to the new adapted requirement is one way to measure behavioral adaptability (Cheng *et al.*, 2011).

Behavioral adaptability displays the cost-effective level of the adaptation process actualized for the product, and is based on which decision-makers can evaluate the value of adaptation. To determine the effectiveness of implementing adaptation, essential adaptability and behavioral adaptability need to be taken into account synthetically (Cheng *et al.*, 2011). An adaptation with low behavioral adaptability and high essential adaptability is not desired, but conversely, it is desired because it can be realized easily, valuably and conveniently. The method by Cheng *et al.* (2011), discussed above, will be employed in assessing the adaptability of the SWC practices in this research.

4. DISCUSSION AND CONCLUSIONS

SWC techniques have widespread application but their implementation varies with location and is also dependent on the socio-economic conditions of the area concerned. This requires a full understanding of the SWC techniques and being able to answer questions as to which SWC techniques have been implemented successfully in certain areas and whom have they been implemented to or by. The economic efficiency of adopting SWC techniques, compared to conventional practices, needs to be clarified, so that the benefits of adopting them are apparent to the farmer. Because the development of SWC systems and their sustainability are highly site-specific, a more action oriented research that also looks at the different roles of stakeholders may be necessary. Because the characteristics of SWC techniques such as, compatibility, complexity, feasibility and trialability, vary with local socio-economic characteristics of the farmer and environmental benefits, investment in adaptive research is needed to tailor the adoption of these techniques to local conditions.

The methods used to measure adaptability need to reflect the cost of transforming the farmer's current practices to the anticipated new practices. The adaptability of a practice should also reflect the final results to be achieved by the adaptation process. Hence, the measuring tools of the adaptation of SWC practices need to be clear to the farmer, to enable them to apply best-bet options in their production. In southern Africa, studies on the adaptation and adoption of SWC techniques by smallholder farmers in countries like Zambia, Zimbabwe, Malawi and Mozambique, are giving more insight into the factors that may be constraining the adaptation and adoption of SWC techniques.

In South Africa, where this study is based, there is very little literature that gives insight as to why the adoption of SWC techniques by smallholder farmers is low and why SWC technologies are not adapted to improve adoption. Literature has indicated variables like age, family size, the area of the farm, level of education, the use of livestock, training and access to credit as, one of the key factors determining the adoption of SWC techniques. However, these factors are highly dependent on the socio-economic conditions of the areas studies, thus the results obtained can vary depending on the location.

SWC techniques have been adopted to some extend in SSA countries, however, the adoption have been very low among smallholder farmers in South Africa. Deriving the best-bet options from the factors that influence the adoption and adaptation of SWC will assist smallholder farmers take a path that will enable them to adopt this techniques in a sustainable manner. This study is therefore necessary to shed light on the constraints that are faced by smallholder farmers in the adaptation and adoption of SWC techniques.

5. PROJECT PROPOSAL

5.1 Background of study

The many benefits of SWC practices, such as CA and RWH, are undeniable and have led to countless projects and organizations, such as the FAO, governments and NGOs, promoting their adaptation and adoption. Despite the investments made by governments, NGO's and research institutions, the adaptation and adoption of these practices is still low, especially among smallholder farmers (Perret and Stevens, 2003; Giller *et al.,* 2009). In Africa alone, CA has been promoted for more than 30 years, yet the adoption of the technology is still low (Nyanga, 2012; Musara *et al.,* 2012). In southern Africa, the adoption of RWH has been low, even though the benefits of it have been apparent (Mutekwa and Kusangaga, 2006).

For example, in South Africa, CA has been widely adopted in large-scale commercial agriculture; however, for smallholder farmers adoption is still low. The move towards CA by commercial farmers has been driven mainly, for economic and environmental reasons (Johansen *et al.,* 2012). In southern African countries, like Zambia, Zimbabwe and Malawi where the adoption of CA is increasing, it has been characterized as partial (Nkala *et al.*, 2011). There has been little adoption of CA, but rather adaptation that is dependent on the local socio-economic conditions, as it has been observed that some farmers only use a portion of their farm to experiment the 'new' technology, instead of applying it completely (Nkala *et al.,* 2011).

These facts have been the main drivers of this research, as it will seek to answer questions as to why the adaptation and adoption of SWC practices is still low among smallholder farmers, despite the investment in promoting their benefits. The study investigates factors and challenges faced by the smallholder farmers that are impeding the adaptation and adoption of these practices and how the adoption of the practices can be assessed to get the best-bet practices to be implemented by the smallholder farmers in KwaZulu-Natal, South Africa.

5.2 Aims and Objectives

The aim of the project is to determine and assess the factors that are affecting the adaptation and adoption of soil and water conservation practices by smallholder farmers and how the adoption of the technologies can be assessed to get the best-bet practices to be implemented by the small-holder farmers in KwaZulu-Natal, South Africa.

The project has three specific objectives:

- Objective 1: To identify the CA practices currently used by and available to the small-holder farmers.
- Objective 2: To determine the adaptation and adoption of SWC practices used by the smallholder farmers.
- Objective 3: To derive the best-bet options for conservation agricultural practices, to the socio-economic conditions of the smallholder farmers.

5.3 Methodological Approach

5.3.1 Study site

The Emmaus area is located in Bergville and lies in the foothills of the Drakensberg Mountains in the province of KwaZulu-Natal. Emmaus falls under the Okhahlamba Local Municipality, which is under the Uthukela District Municipality. Soil erosion, nutrient depletion and low soil organic matter are major soil productivity and agricultural production limiting problems in this area (Smith, 2006). The geology of the area is made up of the sandstone and mudstone of the Tarkstad formation, Beaufort Group in the west and by shale and sandstone of the Estcourt formation, Beaufort Group in the east (Smith, 2006). Seven major soil patterns are evident in the soils derived from the dark grey shale, siltstone and sandstone of the Estcourt Formation. Two of the soil patterns comprise soils of major agricultural importance, in terms of dryland crop production. The first is a red and yellow apedal soil pattern with Hutton, Clovelly and Griffon soils being dominant and with Katspruit, Mispah and Glenrosa soils being subdominant (Smith, 2006; Dlamini *et al.*, 2011).

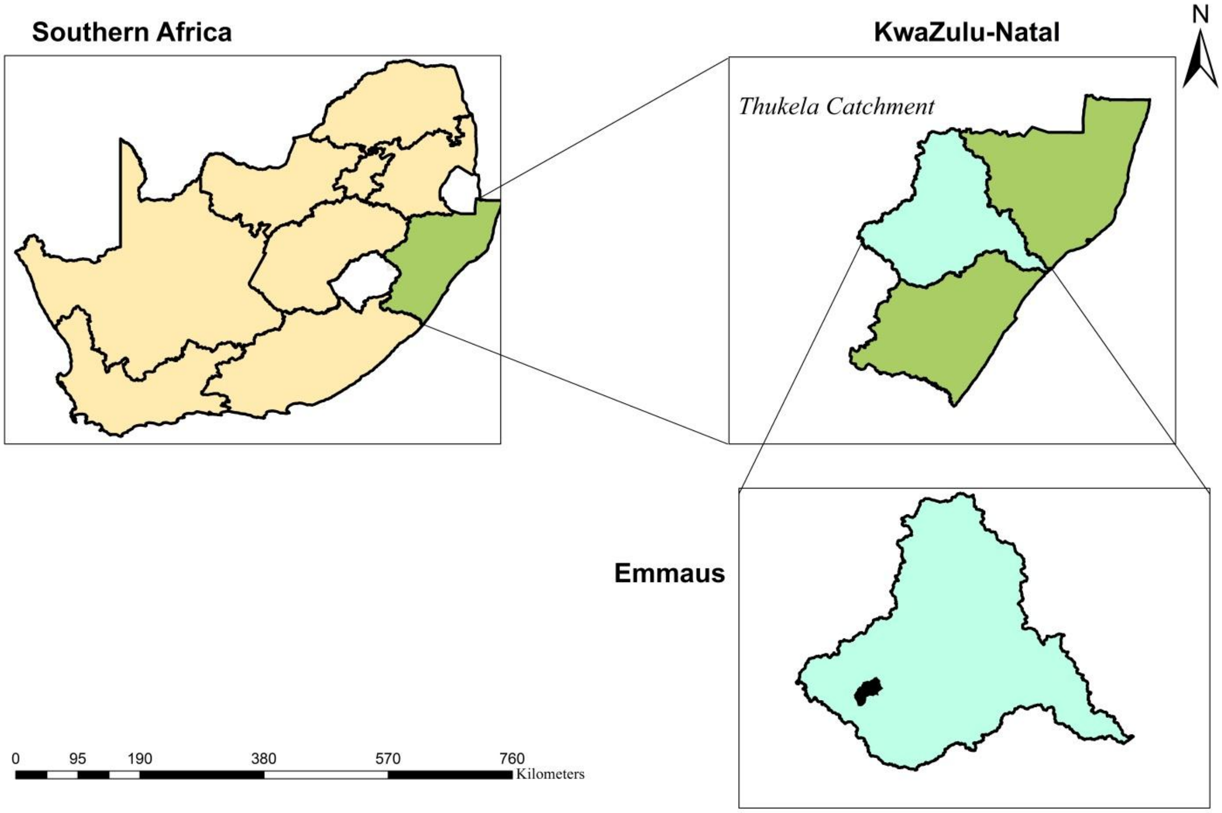

Figure 5.1 A map of the study area

The altitude of the study area ranges from 1000 m in the east to about 1700 m in the foothills of the Drakensberg. The mean annual precipitation of Bergville has been 684 mm per annum over the past 30 years with a potential evaporation of 1600 mm per annum (Dlamini *et al.*, 2011). Agricultural production in the Emmaus area consists of smallholder and commercial farmers. The main crops farmed in this place are maize, millet, dry bean, sorghum and potato (Anderson *et al.*, 2009). The smallholder farmers usually have maize plots and home gardens, where they farm vegetables. The homestead gardens are usually less than 0.5 ha in size with the maize plots being 1 to 10 ha in size and are situated just outside the household homesteads (Anderson *et al.*, 2009). The smallholder farmers rely heavily on natural rainfall, as they practice dryland agriculture with the home gardens watered by the water collected from the rain water harvesting tanks provided by the Department of Water Affairs. The livestock is used in agricultural production, as the cattle provide draught power for ploughing and the cattle manure is used as a form of fertilizer.

5.3.2 Research approach

A pilot study will first be undertaken in the Emmaus area. The study will serve as a test for the feasibility of the research, to assess whether it can be accomplished within the assigned time and the scale required for obtaining data representative of the study area. This study will also assist in testing the questionnaire, to see whether the participants are able to answer the questions asked. The data collected from this pilot study will also assist in identifying the challenges that may be encountered in the course of the research.

A random sampling strategy will be employed in this research. The smallholder farmers will be selected in a way that will be representative of the smallholder population in the study area. A sample of 300 smallholder farmers will be randomly selected from 11 villages in Emmaus, Bergville. Stratified random sampling will be applied, where smallholder farmers that practice SWC techniques will be selected for interviews, based on the adaptation and adoption of the SWC techniques they practice. The data will be collected in the form of face-to-face interviews with farmers, questionnaires and farmers group meetings.

Enumerators will be employed to collect the data and will be trained before the data collection. To ensure the validity of the data, the questionnaires will be reviewed by experts and also by doing a pilot study before the actual study. The reliability of the data will be ensured by triangulating the data. Consent will be sought from participants in this study. Permission to conduct interviews and the questionnaire will be requested from the participants and the purpose of the study will be explained to them before the interview process. Ethical clearance measures of the University of KwaZulu-Natal will be adhered to.

For the three objectives, the methodology to be applied for each objective is as follows:

Objective 1: Methodology 1

The SWC practices currently used by, and available to, the smallholder farmers will be identified by visiting the farmers' fields. This will entail identifying the types of SWC practices used by the farmer and characterizing the different techniques.

Objective 2: Methodology 2

The adaptation of the different identified SWC practices will be evaluated by using an outcome-based adaptation indication. That will entail looking at how the SWC practices have been adjusted and why the adjustments and the effectiveness of the adjustments have been applied. Correlation analyses will be undertaken to determine relationships between the factors that indicate the adaptation of the practices. The adoption of the SWC practices will be determined by using a binary Logit Model. The Model will analyse the factors influencing the adoption of the SWC practices by farmers. The model will use independent variables that will be acquired through questionnaires. The questionnaire will be designed in such a way that it reflects the theoretical model to be used.

Objective 3: Methodology 3

The best-bet options will be determined through the use of a Multi Criteria Decision Analysis (MCDA) that is categorised as a multi-attribute decision-making (MADM) method. The MADM is selected because of its ability to select discrete alternatives (Mendoza and Martins, 2006). Best-bet options in the adoption of SWC practices will be determined through the analysis of the results (adoption) obtained from the Logit Model and correlation analyses (adaptation). The best-bet options will be used to make recommendations that will assist the smallholder farmers.

The research will help better understand key factors in agricultural technology adaption and adoption. The success stories of current smallholder farmers who have adopted SWC techniques successfully, will also be looked at in detail, as a form of a best-bet option that can be employed for a successful adaptation and adoption of SWC techniques. This will enable the farmer to choose a method that will enable them to farm in a sustainable way.

5.3.3 Expected results

A goal or reference level model, like the one in Figure 5.2, which involves a process that seeks to discover options which lead to the desirable goals.

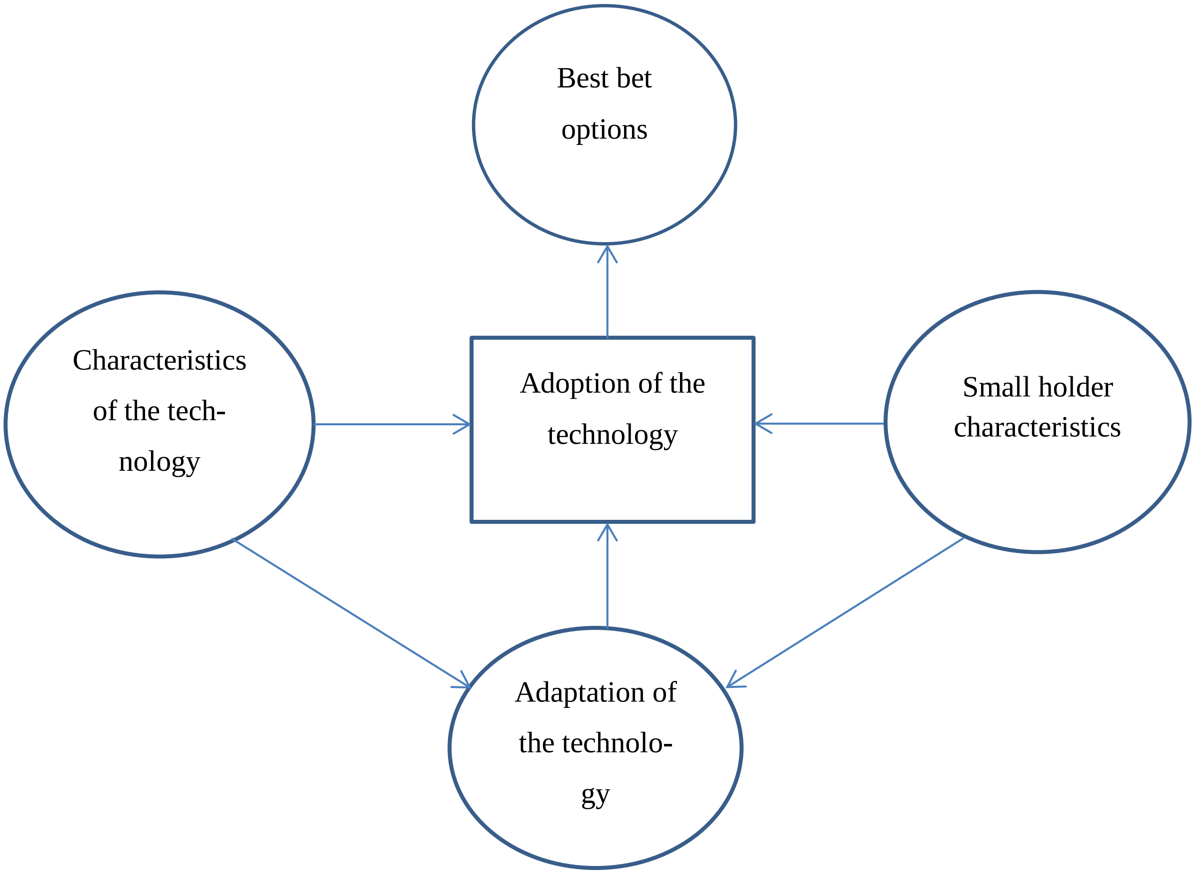

Figure 5.2 A framework indicating the pathway to attaining the best-bet options

Table 5.1 Resource requirements

Resources	Cost
Food for personal consumption	3000
Food for farmers group meetings	2000
Transport	10000
Airtime	2000
Accommodation	10000
Numerators	15750
Total	**42750**

Table 5.2 Project timeline

Tasks (2014)	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**
Proposal and Literature review	■	■	■								
Site selection, data collection and lit review	■	■	■								
Data collection		■	■	■	■	■					
Field work			■	■	■	■	■				
Field work				■	■	■	■				
Analysis of results (best-bet options)				■	■	■	■	■	■		
First draft submission									■	■	■
Final theses submission											■

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7. APPENDIX A

Table 7.1 Empirical studies on the adoption of SWC techniques

Author	**Study area**	**CA technology used**	**Sample/Plot size**	**Data collection method used**	**Method of analysis**
Bayard *et al*.(2007)	Haiti	Alley cropping	120 small scale farmers	Survey through face to face interviews with small-scale farmers	Probability choice model (Probit)
Jara-Rojas *et al*.(2012)	Central Chile	Water conservation practices (drip irrigation, stone walls, elimination of weeds)	331 small scale farmers	Survey through interviews with small scale farmers.	Poisson regression model (PRM), Logit model, Multinomial Logit model (MLM).
Musiwaetal (2012)	Zimbabwe	Conservation farming technology	75 small scale farmers	Purposive sampling through the interview of small scale farmers and NGOs and government departments concerned.	Transcendental Regression Model (TRM) (estimate economic and technical efficiency) and the Logit model.
Neupane *et al.* (2002)	Nepal	Agroforestry	223 households; 82 project and 141 non-project.	Purposive sampling was used where 223 households were surveyed through questionnaires.	Logit model

Adesina *et al.* (2000)	Cameron	Alley farming variants.	256 farmers surveyed from 11 villages.	Stratified random sampling was used to identify the 256 farmers (alley cropping adopters and non-adopters).	Logit model
Bekele and Drake (2003)	Ethiopia	Soil and water conservation structures.	265 farmers	Interviewed individuals using semi-structures questionnaires, group discussions used to develop formal questionnaire.	The multinomial logit.
Sedibe (2004)	Burkina Faso	soil and water conservation techniques	230 small farm households	The 230 farmers were randomly selected from a population census. Questionnaires, discussions and individual interviews were conducted.	Probit regression model
Akudugu *et al.* (2012)	Ghana	modern agricultural production technologies	300 farmers	Household questionnaires were administered.	Logit model

Cary and Wilkinson (1997)	Australia	soil and water conservation techniques	131 farmers	The 131 farmers were randomly selected from a population of 329 farmers.	Logit model
Tadesse and Belay (2004)	Southern Ethiopia	Soil Conservation Measures (Fanyajuu)	120 househeads	120 farmers in which 80 were from the treated and 40 from non-treated sites.	Logit model
Kabanyoro *et al.* (2013)	Uganda	Intercropping	171 households	Household survey on socio-economic factors.	Logit model