

Review

Conservation Agriculture for smallholder farmers in the Eastern Cape Province of South Africa: Recent developments and future prospects

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The current interest in Conservation Agriculture (CA) technologies is a result of the need to reduce excessive land degradation in most crop producing areas as well as, to enhance sustainable food production. Cover crops that are usually grown under CA to provide soil cover may offer secondary benefits depending on the farming system. The concept of growing cover crops is a relatively new phenomenon to smallholder farmers. Production of large biomass yields and weed suppression from cover crops were the major challenges affecting success and uptake of CA technologies by smallholder irrigation farmers. Coupled with this, low soil fertility limit maize productivity and reduce water use efficiency on smallholder irrigation schemes in what is largely a water strained agro-ecology in the Eastern Cape (EC) Province of South Africa (SA). While cover cropping can increase maize productivity, benefits of different types of mulch are not well understood, leading to challenges in selecting the most appropriate cover crop species to grow. With respect to any new technology, smallholder farmers are more interested in the economic benefits. This paper reviews recent research and extension efforts into CA and the future prospects of this technology in the EC.

Key words: Conservation agriculture, cover crops, nitrogen, phosphorus, smallholder farmers.

INTRODUCTION

Small-scale irrigation farmers have been faced by a myriad of several production challenges resulting in low levels of production. The term 'smallholder farmers' refers to their limited resource endowments, particularly land. They cultivate 10 ha or less and also manage livestock. Smallholders represent a large number of holdings in many developing countries and their numbers have increased in the last two decades, accounting for a majority of rural employment (Dixon et al., 2004). The sub-optimal performance of many small-scale irrigation schemes has been largely accredited to several socio-economic, political, climatic, and edaphic constraints (Bembridge, 2000). Many SA irrigation schemes face viability problems as farmers are often not able to repair irrigation equipment, and thus, have an over reliance on government grants and communal payment methods for services such as electricity.

In a recent study (Fanadzo et al., 2010), it was revealed that farmers in Zanyokwe Irrigation Scheme

(ZIS) earn well below the poverty datum line and are considered poor. Low crop productivity from ZIS was explained by inadequate tillage services, lack of access to fertilizers, seed, chemicals and irrigation equipment. These factors have threatened the survival and sustainability of small-scale irrigation schemes. According to Bembridge (1996), maize yields of less than 2 t/ha are common in small-scale irrigation schemes. Maize is both South Africa's staple food and most extensively (1.7 to 4 million hectares) grown field crop, followed by sugarcane and wheat (FAO, 2006). Maize in particular is often grown in areas of marginal rainfall or soil depth. In the past, a net exporter of food, SA's increasing population densities and past mismanagement of arable and pasture lands are threatening South Africa's natural resource base and national and household food security (Fowler, 1999).

Land degradation and excessive soil erosion accompanied with the formation of large gulleys has reached an

alarming scale in the Eastern Cape. The main causes of this land degradation have been reported to be continuous conventional tillage. Conventional tilling where the soil is inverted using various forms of ploughing leads to formation of compaction (plough pans) and accelerated decomposition (loss) of organic matter (Laker, 2004; Mills and Fey, 2004). Moreover, crop residues are removed or burned that leave the soil unprotected to climatic hazards such as rains, wind and sun. Increasing demand for arable land from a rapidly growing population has led to ever-shorter fallow periods, which no longer enable the restoration of soil fertility. Declining soil fertility and increasing weed pressure increase the workload of farmers, while yields persistently decline (Mandingana et al., 2005; Steiner and Bwalya, 2001). In the 1970s to 1980s, researchers in SA tried to promote minimal tillage to address increasing land degradation with limited success (Fowler, 1999). The missing element found in these reduced tillage systems was a permanent soil cover (Fowler, 1999; Derpsch, 2003). It could be argued that farmer uptake of developed technologies was low, probably because these did not fit appropriately into their system nor offer sufficient economic incentives.

There are about 317 smallholder irrigation schemes in SA, accommodating up to 250,000 smallholder irrigators (Bembridge, 2000). For some farmers, water availability at the source for irrigation is not limiting, resulting in over irrigation due to lack of technical knowledge. However, cropping intensity on smallholder irrigation farms is low, < 48% and farmers rarely plant winter crops such as cabbage, carrot and onion leaving the land fallow throughout the winter (5 to 6 months) and thereafter, plant the summer maize crop. In a three-year study, it was reported that only 6.6% of the total land area was planted to winter crops at ZIS (Fanadzo et al., 2010). Reasons for low cropping intensities included infrastructure deficiencies, poor operational and management structure, lack of technical knowledge and lack of financial resources (Fanadzo et al., 2010).

CONSERVATION AGRICULTURE

Agricultural scientists and policy makers in SA have tried to borrow from the Latin American experience on conservation agriculture (CA) to reduce land degradation (Allwood, 2006). The three pillars of CA are: i) minimal soil disturbance through zero tillage and direct drilling, ii) ecologically viable crop rotations and iii) permanent soil crop cover provided by cover crops. Conservation agriculture differs from other sustainable practices such as agroforestry in that, there is no tillage and plant residues are not incorporated into the soil but are left to decompose on the soil surface (Nair, 1993; Derpsch, 2003). There has been confusion on the definition of CA and differences with conservation tillage (CT). To add to the confusion, the term 'conservation agriculture' is a

recent term introduced by the FAO (Hobbs, 2007). Conservation tillage has been defined as follows: a collective umbrella term commonly given to no-tillage, direct-drilling, minimum-tillage and/or ridge-tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30% surface cover by residues characterizes the lower limit of classification for conservation-tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients (Fowler and Rockstrom, 2001; Baker et al., 2002). According to Hobbs (2007), CT uses some of the principles of CA, but has more soil disturbance than CA.

Farmers in the Lempira area of Honduras have reported some of the benefits of CA as follows; improved soil moisture conservation, which permits a good development of the crop, even in very bad conditions, less soil erosion (even during the heavy rains of hurricane Mitch in 1998). The soil becomes more fertile and the effect of fertilizers on the production is higher and agricultural production is higher than in traditionally managed plots (FAO, 2001). Knowledge sharing between Latin American countries and South Africa has been minimal. Consultants with CA experience in Brazil have been involved in CA work in South Africa (Derpsch, 2003) while some researchers have visited Brazil to learn from their experiences (Allwood, 2006).

LOCAL CLIMATE IN THE STUDY AREA

Low rainfall is a major challenge to sustainable crop production in the semi-arid climate of the EC. The study area has a warm temperate climate and a mean altitude of about 535 m. a. s. l. Mean monthly temperature ranges from 19 to 23°C during the summer season (October to April) and an monthly temperature ranging from 13 to 17°C during the winter season (May to September). The mean annual rainfall is 575 mm, most of which falls during the summer. Only 22% of the mean annual rainfall falls during the winter period.

The whole of SA also receives low rainfall with a mean annual rainfall of appropriately 450 mm (making supplementary irrigation necessary), with 75% of the country receiving less than 600 mm. According to the United Nations Council on Combating Desertification (UNCCD) system for defining dry lands, more than 80 percent of its land surface is classified as semi-arid to arid (FAO, 2006). Even on irrigation schemes, soil moisture is still a challenge due to a critical lack of irrigation equipment and/or the financial resources to acquire irrigation equipment. Farmers share the little equipment available and, during peak crop evapotranspiration demands, serious moisture deficits result affecting crop growth. One solution to this challenge may be providing credit facilities to enable farmers to buy necessary equipment. Another less expensive solution

may be increasing crop water use efficiency (WUE) through use of mulches provided by cover crops.

Knowledge about successful CA technologies is still a challenge for most smallholder farmers. Conservation agriculture is a relatively new technology for smallholder farmers in the Eastern Cape (EC) province. Recent research efforts have investigated CA technologies that smallholder farmers can adopt to alleviate crop production challenges on their farms. The objective of this review was therefore, to analyze these recent developments in optimizing CA technologies for small holder farmers. Future prospects of CA in the EC were also assessed. Recommendations for future research were also given to address some critical knowledge gaps identified in this study.

PRELIMINARY CA TRIALS ON FARMERS' FIELDS

The first no-till experiments in SA started in 1977, and since then, a handful of large scale farmers have adopted no-till systems of production (Derpsch, 2003). The standard of no-tillage technology and the knowledge of the farmer about the system were rated as good and in many instances outstanding. The missing elements found were cover crops and diversified crop rotations (Derpsch, 2003). There was therefore, scope for improving the quality of the no-tillage system in order to achieve long-term sustainability by adding these components. Most of the no-till farmers rotated maize and soybeans on the same piece of land. Addition of cover crops in such systems was hoped would result in improved diversity and reduce pest and/or disease build-up.

Research and CA technology promotion experience for subsistence farmers in the Eastern Cape has had several challenges (Derpsch, 2003). The rainfall in this region averaged about 400 to 600 mm and production systems in these areas are mining the soil by overgrazing and intensive tilling of the soil to plant maize resulting in extensive erosion. These systems are not sustainable. Communal pasture systems are a hindrance for applying no-tillage and applying permanent cover cropping system because cattle and other animals will graze the residues and cover crops, leaving very little cover for the soil. It has been suggested that unpalatable cover crops such as *Vicia dacycarpa*, *Ricinus comunis*, *Canavalia ensiformis*, *Tephrosia* sp., *Crotalaria*s in general (except *C. juncea*) and *Indigofera hirsuta* could be relay seeded or seeded immediately after the main crop (Derpsch, 2003). Fencing of plots is also an avenue for reducing grazing or foraging of cover crops or plant residues by animals. However, because of insecurity of land ownership often leads to unwillingness of small farmers to invest in their land. Suggestions of using living fences have also been made.

On-farm trials conducted on about 13 smallholder sites faced numerous challenges that reinforced farmers to

believe that tilling the soil was a better option. The main reason for the failure of these preliminary CA trials was serious weed problems, which were mainly attributed to *Cynodon dactylon*. The planters that were used on these trials were found to be opening up too wide a planting furrow and bringing weed seeds to the surface to germinate. Effective methods of weed control have to be found, presumably, high cover crop biomass yields will subsequently be able to effectively smother and control weeds. This experience highlighted the importance of mastering the technology on-station before embarking on on-farm trials.

Availability and affordability of no-till equipment is still quite a challenge for smallholder farmers (Derpsch, 2003). Low rainfall in many areas of SA makes improved water infiltration and conservation remain the most decisive production factor in relatively light and poor soil conditions. It has been argued that in these areas until such a time that a significant mulch cover can be established (constituting a prerequisite for zero tillage), a minimum/strip system (direct ripping and planting technology) may be considered a viable option to replace a ploughing (Ficarelli et al., 2011). This, as it is argued, would be a promising stepping-stone towards the adoption of a fully-fledged no-tillage system. Increasing demand for arable land from a rapidly growing population has led to ever-shorter fallow periods, which no longer enable the restoration of soil fertility. Declining soil fertility and increasing weed pressure increase the workload of farmers, while yields persistently decline (Steiner and Bwalya, 2001). The model that was proposed to be used for CA, with respect to tillage, ranged from conventional tillage to reduced tillage and then zero tillage.

RECENT EXPERIENCES WITH CA TECHNOLOGIES

Presently, most work on station in EC, mostly at the University of Fort Hare, has shown that CA can be practiced successfully by smallholder irrigation farmers. Conservation agriculture is being promoted as a technology that will promote increased productivity with low external inputs. Previous studies and demonstrations in the Eastern Cape by the Department of Agriculture in CA had seemingly failed. The single most important factor implicated for this failure was poor biomass production by the cover crops.

Previously, the choice of a cover crop species to grow was not informed by clear objectives to be achieved. Cover crops which are better adapted to the warm-temperate climate in the Eastern Cape were therefore required. Cover crop fertilization was also evaluated as a strategy to improve biomass production. Soils with inherent low soil fertility may limit cover crop biomass production (Derpsch, 2003). Recent studies have quantified some of the benefits achieved by the different cover crops species with respect to weed control, soil

fertility improvement, soil water conservation, maize yields and economic returns (Murungu et al., 2010, 2011a, b; Musunda, 2010; Ganyani, 2011).

WINTER COVER CROPPING

Oats, grazing vetch and forage peas produced high biomass yields of 13873, 8945.5 and 11073 kg/ha respectively, averaged over the two seasons (Murungu et al., 2010; Musunda, 2010). The biomass yields from these cover crops resulted in other secondary benefits on the subsequent maize crop (Murungu et al., 2011b; Musunda, 2010). The biomass yields obtained from lupins were too low to sustain any meaningful CA technology in the EC. Derpsch (2005) reported that farmers in Brazil aim to achieve biomass yields of between 6 to 10 t/ha to ensure success of CA systems through weed suppression and reduced soil erosion. Vagen et al. (2005) concluded that biomass yields of at least 5.3 t C ha/year were able to increase soil organic matter (SOM). In the EC carbon uptake by oats and grazing vetch were in the range of 5 t C/ha or even greater for oats, implying that these cover crops may substantially increase SOM. It may also be important to note that oats responded more to fertilization as compared to the legume cover crops. Biomass yields for oats was grown in highly degraded soils, with critically low soil nutrients and organic matter and may be fertilized to increase the soil organic matter levels before other cover crops may be recommended (Murungu et al., 2010). When introducing CA technologies to a particular area, there should not be an over-reliance on one particular cover crop species (Fourie et al., 2001). The cover crops may need to be rotated to avoid weed, pests or disease build-up. It is therefore, important to have a variety of species for cover cropping. Serious pest and disease problems were not observed on cover crops growing in the EC. Ability to produce high biomass yields and also control winter weeds by actively growing cover crops and also ability to control weeds as residues in a summer maize crop are major considerations. Oats and grazing vetch are more superior to faba bean and lupins with respect to biomass yields (Murungu et al., 2010). Forage peas were observed not to be as effective as oats and grazing vetch in controlling weeds but were able to produce a lot of biomass. Forages peas may therefore, be an option in the later cycles of growing cover crops because of its high biomass production. This is because weed dry mass drop from the initiation of CA onwards, as observed in this study and elsewhere (Bàrberi and Mazzoncini, 2001). While oats and grazing vetch maybe used in the initial stages of introducing CA, as weed densities decrease because of CA, forage peas may be a viable alternative in the rotation of cover crops because of its high biomass production.

The small-holder sector grazing of cover crops by

animals may reduce the total amount of biomass that can be used as mulch. This in-turn will also reduce the potential N that is available to the succeeding crop. Plots on irrigation schemes in SA are fenced which allows farmers on these schemes to grow winter cash crops such as cabbages and they are also able to limit or stop any grazing that can occur on their winter crops. These farmers can therefore, grow winter cover crops without the cover crops being grazed. Research effort may also be needed for integrated cover crop-livestock production systems as most farmers own ruminants such as cattle, goats and sheep. During the dry periods, when cover crops are grown, farmers may want to let their animals graze the growing cover crops. Cover crops with ability to produce high biomass yields even after grazing may be important in these systems. Effects of the frequency and intensity of grazing over cover crops by farm animals on final biomass production, weed control and nutrient contributions to a succeeding crop may be issues that require further investigation. Oat and grazing vetch residues resulted in improved weed control and soil moisture conservation. This was probably related to the high biomass produced by these cover crops. Teasdale (1996) reported that high biomass production had a significant correlation to weed control.

SUMMER COVER CROPPING

In other studies, summer cover crops produced much lower biomass yields (> 3 t/ha) when strip-intercropped or relay-intercropped with maize compared to the sole crops. These biomass yields did not result in any meaningful contribution to a subsequent crop in terms of enhancing the soil N status as well as, weed control (Murungu et al., 2010; Musunda, 2010). The low biomass yields by summer cover crops coupled with long fallow periods may explain the lack of benefits derived from growing summer cover crops. In other systems, (Jeranyama et al., 2000; Lupwayi et al., 2000), summer cover crops yielded higher biomass yields in maize intercrops and were able to make meaningful N contributions to the subsequent crop. The time of introducing cover crops into a maize crop is one factor that may explain the differences in biomass yields in relay intercrop systems. Also, the winter in the EC is relatively wetter allowing weeds to grow and take up any nutrients released from decomposing summer cover crops. Further research on optimizing the time of introducing summer cover crops into a maize crop may be necessary to increase biomass yields. In contrast to intercropped summer cover crops, sole crops produced high biomass yields (up to 9 t/ha). The growing of winter cash crops after a summer cover crop may offer as much benefits to the winter cash crop as those experienced with maize growing on grazing vetch residues. More research on this may however, be necessary.

Intercropping maize with summer cover crops was not able to reduce weed densities in the subsequent crop. The farming system which allows a long fallow period may explain this. Soil moisture was not measured in the strip-intercropping study. However, maize grain yields were reduced in a drier year where irrigation problems were experienced. Increased competition for water between the maize and the cover crops may explain the low maize yields.

COVER CROP DECOMPOSITION, NITROGEN AND PHOSPHORUS RELEASE

For winter grown cover crops, mass loss over time (decomposition) was in the order grazing vetch > forage pea > oats (Murungu et al., 2011a). The higher C: N ratio, higher lignin and polyphenols in oats were significantly associated with its lower rate of decomposition. After a month of exposure in the field, grazing vetch lost about 50% of its original weight, forage peas about 42%, while oats lost about 35% for the same period. The fast decay observed immediately after placing plant materials in the field may be explained by leaching of water soluble constituents of the plant materials (Ibewiro et al., 2000). The removal of water soluble constituents is a factor that will influence decomposition. Reported rates of decomposition are much lower (30%) for summer-grown cover crops than for winter cover crops. The difference in the time of placing the litter bags for summer and winter cover crops may explain the differences in decomposition rates for the two types of cover crops. Summer-grown cover crops were left to decay during the autumn and winter months which experience much lower rainfall and temperatures than the summer. Winter grown cover crops on the other hand, were left to decay in a much warmer and wetter environment and this may have led to their faster rates of decomposition. The rate of decomposition includes the effects of the environment (air temperature and precipitation) and the bio-chemical composition of the plant materials (Ruffo and Bollero, 2003). The higher temperatures and moisture in summer may encourage more activity by soil organisms resulting in higher decomposition rates.

Grazing vetch improved soil N, maize dry mass accumulation and N uptake by maize. These benefits may prove to be very important in systems where farmers only apply at most 60 kg N/ha to their maize crop. One particularly interesting result from this study was that unfertilized maize grown on grazing vetch residues had higher yields as compared to fertilized maize plots with either oats or lupin residues. This may imply that decomposing grazing vetch residues were able to compensate for the lack of maize fertilization by releasing N and modest extractable P amounts. While grazing vetch performed well in on-station trials, optimal N management regimes need to be elucidated. Grazing vetch

contributes N to the succeeding crop but how much extra N may need to be added to the maize to maximize yields and gross margins may need further study. Miguez and Bollero (2005) have shown that while legume winter cover crops increased N uptake and yield in maize when no nitrogen was applied, this benefit decreased with application of fertilizer. It may therefore, be envisaged that less fertilizer application may be required to maximize economic returns of maize growing on grazing vetch residues.

Winter legume cover crops such as grazing vetch were able to increase soil inorganic N levels. Summer cover crops grown in association with maize did not result in an improved soil inorganic N in the subsequent season. While both the winter and summer legumes had low C/N ratios (< 16) the low summer cover crop biomass yields and the farming system employed could largely explain the differences observed in the performance of winter and summer cover crops. Winter legumes were grown as sole crops and produced more dry mass per unit area and also N uptake was much greater. For winter legumes, only one month after the termination of the cover crops, maize was planted in the residues. However, summer legumes produced lower biomass yields per unit area when grown in association with maize. The summer legumes also were left in the field for a long fallow period of up to six months. A fallow period of 5 to 6 months could have allowed enough time for the legume cover crops to decompose and release nutrients and also allowed weeds to grow which may have taken up nutrients compromising the efficiency of the system with respect to nutrient contributions to the next maize crop. Nutrient release from decaying plant materials must be synchronized with nutrient uptake by a follow-up crop. Rains received (about 255 mm) during the fallow period may also leach nutrients such as N. Legume cover crops have been reported to improve soil N and making substantial nutrient contributions to maize growth in Nigeria and Tanzania (Kalumuna et al., 2001; Ibewiro et al., 2000).

FINANCIAL IMPLICATIONS OF CA TECHNOLOGIES

Farmers are often unwilling to make large economic investments to cover crops because of the lack of cash and limited access to credit. Grazing vetch produced high biomass yields with little or no fertilizer inputs. On the other hand, while oats produced the highest biomass yields of up to 14 t/ha, they required some investment in fertilizer (45 kg N/ha) to achieve this yield. Another advantage of grazing vetch over oats was the higher N uptake of 345 kg N/ha compared to oats which took up 253 kg N/ha. This higher N uptake by grazing vetch was able to fix approximately 112 kg N/ha which was translated to 400 kg AN (28% N) with a current market value of US\$220.00. In low external input systems that

are found in most smallholder irrigation schemes, this may be very significant as farmers are known to apply meagre fertilizer amounts, about 60 kg N/ha to their summer maize crop (Fanadzo et al., 2010). Costs for growing winter cover crops ranged from US\$350/ha for the unfertilized cover crops US\$670/ha for fertilized cover crops (Murungu et al., 2010). Oats are more expensive to produce because of the need for substantial fertilization to ensure high biomass production. This may make it unfavourable for resource-limited farmers. Unfertilized maize growing on grazing vetch residues resulted in the greatest gross margin (GM) and benefit: cost (B: C) ratios. This makes grazing vetch particularly favourable for farmers in low external input systems.

Farmers in low external input production systems, such as those in South Africa's smallholder irrigation schemes will demand multiple benefits from cover crops. Reduction of land degradation may not necessarily be their overriding concern. The contribution of cover crop residues to overall crop productivity is of particular importance to these farmers. Grazing vetch fixed approximately 111.5 kg N/ha which may translate to about 400 kg lime ammonium nitrate (28% N) with a current market value of about US\$220.00. The combined effect of grazing vetch residues on soil N improvement and weed suppression resulted in the highest benefit to cost ratio of 1.9 when maize was planted without fertilization. This may make grazing vetch particularly more attractive than oats since oats require a significant investment in fertilizers while grazing vetch require less fertilization for its growth. However, smallholder irrigation farmers maybe reluctant to plant any crop that will not yield food, feed or cash harvest. To them, it may be a luxury to plant a cover crop without any direct harvest. One alternative would be to graze these cover crops, leaving some residue on the surface and leaving roots in the soil which would give a good part of the N benefit after a legume. Performance of cover crops in integrated crop/livestock systems may require further study. Using some cover crops that have a food/cash harvest such as soybeans and cowpeas is also a viable option.

CONCLUSION AND RECOMMENDATIONS

The following recommendations can be made from the current research work that has been completed:

1. Farmers may use oats and grazing vetch for high biomass, C and N yields, and winter weed control.
2. Use of grazing vetch may benefit smallholder farmers since it results in the highest economic returns with minimal fertilizer inputs during cover crop growth and maize growth.
3. Farmers growing maize on oats residues may need to apply more fertilizer than maize growing on legume cover crops.
4. Planting summer cover crops and allowing a winter fallow period offer little opportunity for farmers who may wish to improve soil N for a maize crop in the following summer.
5. More studies on fertilizer management for crops growing on oat and grazing vetch residues are required.
6. Growing summer legume cover crops with a view of planting winter food/cash crops may offer better prospects for optimizing nutrient release and uptake by crops in smallholder cropping systems. However, more research on this may be required.
7. Performance of cover crops in integrated crop/livestock systems may require further study. In particular, effects of the frequency and intensity of grazing over cover crops by farm animals on final biomass production, weed control and nutrient contributions to a succeeding crop may be issues that require further investigation.
8. On-farm research that includes farmer evaluations need to be conducted.
9. More research on cover crops with direct food and/or economic benefits is needed.

REFERENCES

- Allwood J (2006). Contribution to the conservation agriculture research program development workshop, Eastern Cape Province Department of Agriculture. In: Brussaard L, Hebinck P (eds) Beyond Conservation Agriculture: A science program on the transition from promise to practice. Department of Agriculture, Pretoria, South Africa. pp. 12-17.
- Baker CJ, Saxton KE, Ritchie WR (2002). No-tillage Seeding: Science and practice. 2nd Edition, CAB International, Oxford, UK.
- Bärberi P, Mazzoncini M (2001). Changes in weed community composition as influenced by cover crop and management system in continuous corn. *Weed Sci.* 49:491-499.
- Bembridge TJ (1996). Small-scale farmer irrigation schemes in South Africa. In: Backeberg C (ed) Policy proposal for irrigated agriculture in South Africa. WRC Report, Pretoria, SA, pp. 19-26.
- Bembridge TJ (2000). Guideline for rehabilitation of small-scale irrigation schemes in South Africa. Water Research Commission, Report no. 891/00, Pretoria, South Africa.
- Derpsch R (2003). South Africa Report, Promotion of conservation agriculture. Project Number TCP/SAF/2902. National Department of Agriculture Final Report. Eastern Cape Province, South Africa.
- Derpsch R (2005). The extent of Conservation Agriculture adoption worldwide: Implications and impact. Paper presented to III World Congress on Conservation Agriculture, Nairobi, Kenya, October 2005. <http://www.fao.org/ag/ca/en/www.rolf-derpsch.com>.
- Dixon J, Tanyeri-Abur A, Wattenbach H (2004). Framework for analysing impacts of globalization on smallholders. <http://www.fao.org/docrep/007/y5784e/y5784e02.htm>.
- Fanadzo M, Chiduzo C, Mkeni PNS, van Der Stoep I, Stevens J (2010). Crop production management practices as a cause for low water productivity at Zanyokwe Irrigation Scheme. *Water South Afr.* 36:27-36.
- FAO (2001). Conservation agriculture: Case studies in Latin America and Africa. <http://www.fao.org/DOCREP/003/Y1730E/Y1730E00.HTM>.
- FAO, (2006). Agriculture, Biosecurity, Nutrition and Consumer Protection Department. Conservation Agriculture. <http://www.fao.org/ag/cs/1b.html> (Accessed on 20 December 2009).
- Ficarelli PP, Chuma E, Ramaru JM, Murwira K, Haggmann J (2011). Strengthening Local Organizations for Conservation Agriculture – Some experiences from South Africa and Zimbabwe. <http://betuco.be/CA/Conservation%20Agriculture%20-%20Some%20experiences%20from%20South%20Africa%20an>

- d%20Zimbabwe.pdf.
- Fourie JC, Louw PJE, Agenbag GA (2001). Effect of seeding date on the performance of grasses and broadleaf species evaluated for cover crop management in two wine grape regions of South Africa. *South Afr. J. Plant. Soil* 18:118-127.
- Fowler R (1999). Conservation tillage research and development in South Africa. In: Kaumbutho PG Simalenga TE (eds) *Conservation Tillage with Animal Traction*, ATNESA, Harare, Zimbabwe. pp. 51-60.
- Fowler R, Rockstrom J (2001). Conservation tillage for sustainable agriculture: An agrarian revolution gathers momentum in Africa. *Soil. Till. Res.* 61:93-108.
- Hobbs PR (2007). Conservation agriculture: What is it and why is it important for future sustainable food production? *J. Agric. Sci.* 145:127-137.
- Ganyani LM (2011). Evaluating summer cover crop species and management strategies for rain-fed maize based cropping systems in the central region of the Eastern Cape Province of South Africa. M.Sc Thesis, University of Fort Hare, Alice, South Africa.
- Ibewiro B, Sanginga N, Vanlauwe B, Merckx R (2000). Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. *Nutr. Cycl. Agroecosyst.* 57:131-140.
- Kalumuna MC, Mtakwa PW, Rwehumbiza FBR (2001). Influence of cover crops grown in short rains on soil moisture content, mineral N and maize yields in the subsequent long rainy season. In: Msaky JJT, Msumali GP, Rwehumbiza FBR, (eds) *Soil science research and technologies: Foundations for sustainable food security*. Proceedings of the 19th Congress of the Soil Science Society of East Africa. Moshi, Tanzania.
- Jeranyama P, Hesterman OB, Waddington SR, Harwood RR (2000). Relay intercropping of sunnhemp and cowpea into a smallholder maize system in Zimbabwe. *Agron. J.* 92:239-244.
- Laker MC (2004). Advances in soil erosion, soil conservation, land suitability evaluation and land use planning research in South Africa, 1978-2003. *South Afr. J. Plant. Soil* 21:345-368.
- Lupwayi NZ, Girma M, Haque M (2000). Plant nutrient contents of cattle manures from small-scale farms and experimental stations in the Ethiopian highlands. *Agric. Ecosyst. Environ.* 78:57-63.
- Mandingana OT, Mnkeni PNS, Mkile Z, van Averbeke W, Van Ranst E, Verplancke H (2005). Mineralogy and fertility status of selected soils of the Eastern Cape Province, South Africa. *Commun. Soil Sci. Plant Anal.* 36:2431-2446.
- Miguez FE, Bollero GA (2005). A review of corn yield response under winter cover cropping systems using meta-analytic methods. *Crop Sci.* 45:2318-2329.
- Mills AJ, Fey MV (2004). Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *South Afr. J. Plant Soil* 21:388-398.
- Murungu FS, Chiduzo C, Muchaonyerwa P, (2010). Biomass accumulation, weed dynamics and nitrogen uptake by winter cover crops in a warm-temperate region of South Africa. *Afr. J. Agric. Res.* 5:1632-1642.
- Murungu FS, Chiduzo C, Muchaonyerwa P, Mnkeni PNS (2011a). Mulch effects on soil moisture and nitrogen, weed growth and irrigated maize productivity in a warm- temperate climate of South Africa. *Soil. Till. Res.* 112:58-65.
- Murungu FS, Chiduzo C, Muchaonyerwa P, Mnkeni PNS (2011b). Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for a smallholder farming system in South Africa. *Nutr. Cycl. Agroecosyst.* 89:115-123.
- Musunda BZ (2010). Evaluation of cover crop species, multiple cropping strategies and planting dates for high biomass yields, weed suppression and maize yields under irrigation in the Eastern Cape Province of South Africa. MSc Thesis, University of Fort Hare, Alice, South Africa.
- Nair PKR (1993). *An Introduction to Agroforestry*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Ruffo ML, Bollero GA (2003). Modeling rye and hairy vetch residue decomposition as a function of degree days and decomposition days. *Agron. J.* 95:900-907.
- Steiner KG, Bwalya M (2001). The African Conservation Tillage Network Enhancing conservation tillage in Africa. I World Congress on Conservation Agriculture. Madrid, 1-5 October, 2001.
- Teasdale JR (1996). Contribution of cover crops to weed control management in sustainable agriculture systems. *J. Prod. Agric.* 9:475-479.