Agro-ecological attributes of Conservation Agriculture for sustainable land use

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ABSTRACT

Agriculture faces a dual challenge: increasing food production without further sacrificing the environmental integrity. Sustainable land management (SLM) is fundamental to addressing this challenge. In this paper key agro-ecological attributes of SLM are reviewed. These are conservation and efficient use of water and nutrients, maintenance and/or increase of soil carbon; crop diversification and preservation of biodiversity, and enhancement of resilience to external shocks, in particular climate change. The practice of conservation agriculture, which is increasingly considered to have a high potential as a sustainable cropping practice, is evaluated against these key attributes.

INTRODUCTION

Since the 1960s worldwide growth in agricultural production has been tremendous, estimated at 145% (Pretty, 2008). A rising world population to about 9 billion by 2050, combined with changing diets resulting from increased consumption of meat products, will require a further growth of agricultural production. Current food production, expressed in grain equivalent (GE), is estimated at about 7 GT GE. Future demand for the 9 billion people will rise to about 12 GT GE (Van Ittersum, 2011). A further challenge is that this needs to happen without further negative consequences for the environment. Indeed, it is now clear that intensification and specialization of agricultural production accomplished through the use of high-yielding crop varieties, chemical fertilizers and pesticides, irrigation, and mechanization have had a negative impact on the environment and on ecosystem services. Increasing environmental concerns have laid emphasis on the need to more sustainable agricultural methods (Matson et al., 1997).

Sustainable land management (SLM) is seen as fundamental to reconciling increased world food production with greater protection of the environment. Several definitions of SLM exist and many analogous concepts or frameworks have been developed, including ecological intensification (Cassman, 1999), eco-efficient agriculture (Keating et al., 2010), agro-ecology (Altieri, 2002) and evergreen agriculture (Garrity et al., 2010). In the simplest terms SLM is 'the management of land to meet present needs without compromising the ability of future generations to meet their own needs' (Cowie et al., 2011). Essential to SLM are production practices that put emphasis on integrated land, nutrient, and water management. Innovative cropping systems must be designed that rely on principles of the integrated management of soil fertility (e.g., Vanlauwe et al., 2010), of weeds, pests and diseases (e.g., Way and Emden, 2000), on soil conservation practices such as mulching, minimum or no-tillage (e.g., Kassam et al., 2009), on associations of plant species in space and time (e.g. Malézieux et al., 2009), and that exhibit less vulnerability to climate and/or market variability and change.

This paper concentrates on the agro-ecological dimension of innovative cropping systems for sustainable land use management, but bearing in mind that the socio-economic and institutional dimensions of sustainability are equally important for an efficient promotion and adoption of new agricultural production systems. I first present the general agro-ecological attributes of SLM. These attributes, which show close interlinks and are often synergistic, form a conceptual basis for the evaluation and design of innovative cropping systems. As an example, I then evaluate the agro-ecological performance of conservation agriculture (CA) as a strategy for sustainable use of land. CA is increasingly considered as a promising option for coping with the need to increase food production on the basis of more sustainable cropping practices (Hobbs, 2007; Kassam et al., 2009).

INCREASING RESOURCE USE EFFICIENCY

SLM implies the production of more output in terms of productivity and other ecosystem services from the same amount of inputs, hereby reducing negative environmental impacts. This translates in an increased efficiency of the use of the ecological and economic resources (mainly land, water, nutrients, energy, biodiversity, labour and capital). Improving water and nutrient use efficiency have been the focus of much research on cropping systems in recent decades, mostly because water and nutrients (nitrogen and phosphorous) are often the major limiting factors to crop production. A conceptual model illustrating the potential role of SLM in increasing resource use efficiency is shown in Figure 1. The agricultural production response curves are characterised by decreasing returns to increases in the supply of one production factor. In Figure 1 the lowest production functions (B, C and D) depict the efficiencies of current cropping practices in a particular agro-ecological environment and present the yields of a crop across a range of inputs. Innovative land management lifts the output-input relationship (curve A), resulting in e.g. higher crop yields with the same amounts of input. For example, it is estimated that integrated soil fertility management consisting of the combined use of mineral fertilizer with manure or compost, increases the agronomic use efficiency of applied nitrogen fertilizer with about 25% in maize-based systems in sub-Saharan Africa (Vanlauwe et al. 2011).

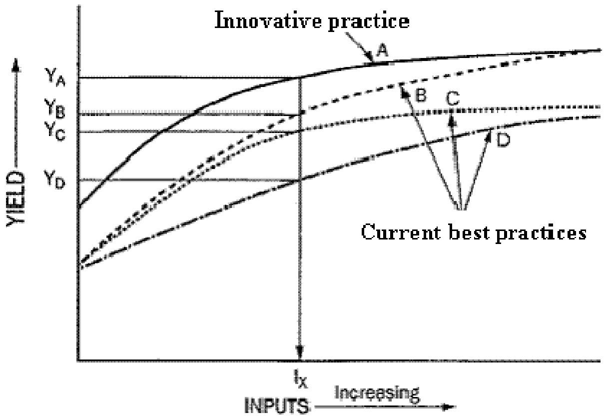

Figure 1: Production functions that relate agricultural output to the level of inputs for current best practices (shown by curves B,C and D) and for an innovative land management practice (curve A) (adapted from Cassman, 1999).

BUILDING SOIL CARBON CONTENT

Soil carbon plays a critical role as a driver of ecosystem services such as plant production, erosion control, biotic activity or pollution diminution, and contributes to increasing resilience to climate variability and change (Lal, 2004). It has been shown that there exists a significant relationship between the level and stability of agricultural production and soil organic carbon content, especially in low-input agricultural systems and on degraded or nutrient-depleted soils (Lal, 2010). For example, an 18-year experiment in Kenya showed that the yield of maize and beans was 1.4 ton ha^{-1} per year without external inputs and 6.0 ton ha^{-1} per year when crop residues were retained and fertilizer and manure were applied. The corresponding soil carbon stocks to 15-cm depth were 23.6 ton ha^{-1} and 28.7 ton ha^{-1}, respectively (Kapkiyai et al. 1999). Most agro-ecosystems have lower soil carbon stocks than the corresponding natural ecosystems, especially when soils are degraded or nutrients are depleted (e.g. Zingore et al., 2005). A critical soil carbon level is essential for good soil quality and efficient use of the inputs, resulting in improved crop production. Although a positive correlation exists between soil carbon and soil biodiversity, there exist little evidence for a predictive relationship between species richness and carbon cycling processes in the soil (Nielsen et al. 2011). An important effect of increased soil carbon is increase in soil aggregation and aggregate stability and consequently a reduction in vulnerability to soil crusting, compaction and erosion, and decrease in water pollution (Lal, 2010). SLM essentially has to include practices that build soil carbon: i.e. that contribute additional organic matter to the soil such as crop residue retention, cover crops, green manure crops, application of fertilizer and manure, measures to correct nutrient deficiencies and soil acidity, and measures that reduce loss of organic matter such as erosion control, no-tillage and no crop residue burning.

MIMICKING BIODIVERSITY

Studies on natural ecosystems have shown that the ability of ecosystems to provide ecosystem services, including productivity, depends both on the number and type of species in the ecosystem. There also exists a consensus on the importance of functional diversity in the stability and resilience of ecosystems (Silver et al. 1996; Hooper et al. 2005). Positive correlations have been found between above-ground biodiversity and primary productivity, nutrient retention and resilience to stresses and shocks in natural ecosystems (eg Loreau et al. 2001). Whilst the role of particularly influential soil species or functional groups on ecosystem services is widely accepted (Lavelle et al., 2006), there is little evidence for a general relationship between soil biodiversity and productivity or soil nutrient cycling. In agro-ecosystems the combination of crops in time (rotations) or space (associations) can increase crop productivity as a result of more efficient use of nutrients and water and facilitating the control of weeds, pests and diseases (Malézieux et al., 2009). It is believed that multispecies systems may maximise beneficial interactions while minimising competition, as a result of facilitation processes and differences in the competitive ability for growth factors between the associated crops.

Some authors (Altieri, 2002; Malézieux, 2012) propose to design cropping systems from natural ecosystems, supporting the idea that for an agro-ecosystem to be sustainable it should mimic the functioning of local natural ecosystems. The hypothesis behind this is that such agricultural mimics can be as productive, pest-resistant and conservative of nutrients as their natural counterparts. For example, agroforestry systems in the sub-humid and semi-arid tropics in which food crops replace the natural understory grass and the original trees of the savannah systems are kept, are believed to be more productive, stable and resilient to seasonal water stress and erratic rainfall than crop monocultures (Van Noordwijk and Ong, 1999).

ENHANCED RESILIENCE

Apart from productivity, an important complementary concept to sustainability is resilience i.e. 'the capacity to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks'(Walker et al., 2010). Resilience is a feature of ecological and social systems and governance is clearly an important determinant of resilience. The capacity of people and institutions to learn and adapt, and to self-organize and reorganize is critical to building ecological and socio-economic resilience, recognising that simple prescriptive approaches are unlikely to be effective in managing complex agro-ecosystems (Walker et al., 2010). In general, the more resilient and more varied the natural, social and human capital assets, the greater are farmers' adaptive capacities to new situations that they have not experienced before, such as a changed climate, and the level of sustainability of their future livelihoods (Pretty, 2008).

A major objective of SLM is to render agro-ecological systems resilient to external fluctuations in climate and markets. Functional aboveground and belowground diversity of species, especially if combined with diversity of responses to stresses amongst the organisms, enhances resilience to the ecosystem. For example, Tilman and Downing (1994) showed that net primary production in more diverse plant communities is more resilient to drought than in monocultures. With regard to climate change, it is believed that SLM practices need to build soil organic matter, maintain vegetative cover and conserve biodiversity (Cowie et al, 2011).

CONSERVATION AGRICULTURE AS A CROPPING PRACTICE FOR SUSTAINABLE LAND USE

Conservation agriculture (CA) is seen as a concept for resource-efficient crop production that is based on an integrated management of soil, water and biological resources combined with external inputs (www.fao.org/ag/ca/). CA is based on three principles that are believed to enhance biological processes above and below the ground. These are: (1) minimum or no mechanical soil disturbance; (2) permanent organic soil cover (consisting of a growing crop or a dead mulch of crop residues); and (3) diversified crop rotations and/or associations. With the implementation of CA one specifically seek to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil with higher crop yields and lower production costs (e.g. Hobbs, 2007; Kassam et al., 2009). It is often claimed that through practicing CA water- and nutrient-use efficiencies of the cropping systems are increased, thereby increasing crop yields and minimizing nutrient losses to the environment (Giller et al., 2009; Kassam et al. 2009). In a recent publication, Rusinamhodzi et al. (2011) showed that CA can result in crop yield benefits in the long-term, but in the short to medium term – and this can be up to 15 years – no yield benefits or yield decreases are just as likely.

In the following sections I evaluate how the practice of CA contributes to the different attributes of SLM practices, outlined above.

Water use efficiency

A major benefit of CA is the conservation of water through reduced soil evaporation and water runoff as a result of mulching with crop residues, giving rise to higher water use efficiencies and better yields (e.g. Thierfelder and Wall, 2009). This effect is in particular important under semiarid conditions. For example, a study (Scopel et al., 2004) showed that under the semiarid conditions in Mexico (525 mm annual rainfall) even small amounts of surface residue are effective at reducing water loss (surface runoff and soil evaporation), giving rise to higher water use efficiencies and better maize yields with smaller risks of crop failure. However, under the wetter conditions of the sub-humid tropical Cerrado region in Brazil (1400 mm rainfall), potential gains in water through a decrease in runoff and evaporation are largely offset by increased drainage losses with possible leaching of nitrogen. As a consequence, under the Cerrado conditions, the impact of crop residue mulching on maize grain yield in CA systems is small and the use of cover crops as nutrient recyclers becomes crucial.

Nitrogen use efficiency

Large amounts of cereal residues with a high carbon:nitrogen ratio that are left on the soil surface temporarily result in a net immobilization of soil mineral nitrogen, although it is expected that this will be less than when residues are incorporated (Corbeels et al., 2003). If repeated additions of large amounts of crop residues lead to a greater soil carbon content, it is likely that also more nitrogen is sequestered into soil organic matter increasing the overall nitrogen use efficiency of the cropping system. In time this may lead to a greater net nitrogen mineralization once a new equilibrium is achieved. Based on a chronosequence study of fields of different age under CA in the Cerrado region of Brazil, Maltas et al. (2007) estimated that soil nitrogen mineralization increased with about 2.5 kg N ha^{-1} $year^{-1}$ under CA practice on an Oxisol. The increase was mainly attributed to the larger soil total nitrogen content. These results indicate that continuous CA cropping has limited implications for nitrogen fertilization recommendations on Oxisols in the Cerrado region, since the extra soil nitrogen supply represents less than 2% of the common N fertilization dose for maize in the region. Key to increasing nitrogen use efficiency is achieving better synchrony between nitrogen supply and crop demand throughout the season (Cassman et al., 2002). Probably the most efficient use of nitrogen can be achieved with intercropped systems. Balde et al (2011) showed in an experiment in the Cerrado of Brazil higher nitrogen efficiency in maize intercropped systems compared to sole maize systems. Part of the nitrogen not taken up by the main maize crop is recovered by the intercrop crop in relay and thus excluded from potential leaching beyond the root zone.

Impact on soil carbon

A meta-analysis of soil carbon storage under CA drawing largely on experiences from North America demonstrated that carbon contents were increased by CA compared with conventional tillage in roughly half of the cases, no change occurred in 40%, and a reduction in soil carbon in 10% of the experiments (Govaerts et al., 2009). A chronosequence study of fields of different age under CA on Oxisols in the Cerrado region of Brazil showed that continuous CA cropping significantly increases organic carbon in the 0–30 cm topsoil layer with 1.9 Mg C ha^{-1} $year^{-1}$. (Corbeels et al., 2006). This is a high value compared to other studies in the region (Batlle-Bayer et al., 2010), which could largely be explained by the intensified cropping practices (2 crops per year) associated with no-tillage. Benefits of enhanced soil carbon with CA are more a function of increased residue carbon inputs than of no-tillage. CA can increase or decrease yields depending on environmental conditions, and in turn, this will impact residue carbon inputs to soils. In addition, erosion control due to the maintenance of a mulch of crop residues is an important mechanism of increased soil carbon storage or decreased soil carbon losses in CA fields compared to CT fields. For example, in a field experiment in Mexico soil carbon erosion losses were reduced by more than half under CA systems as compared to conventional tillage systems. Soil carbon levels increased with about 25 % over a 5-year period under CA compared with conventional tillage both through increased carbon inputs and reduced carbon losses. The increase in soil carbon under CA, however, principally occurred in the top 5 cm of the soil profile (Scopel et al., 2005).

Impact on soil biodiversity

Many studies have demonstrated that soil living communities differ between conventional and no-tillage systems. Larger organisms are in general more sensitive to tillage operations than smaller ones. For example, with regard to macrofauna, no-till often implies an overall increase and diversification of earthworm populations allowing the creation of biological porosity and increased recycling of nutrients (Kladivko, 2001; Lavelle et al., 2006). A field study (Padoa Luiza, unpublished results) in the Cerrados of Brazil showed that that no-till systems hold more diverse and more abundant macrofauna populations (with presence of groups as Oligochaeta, Lepidoptera, Coleoptera Larvae, Diptera, Diplopoda and Dermaptera) than conventional tillage, especially in the top soil layers. However, the quantitative benefits of an increased and more diversified community of soil organisms on plant productivity and its relationship with above-ground biodiversity is still not well understood.

Resilience to climate change

CA has been suggested as a key low-cost strategy to lessen negative impacts on crop production from climate change (Kassam et al., 2009). Results from field experiments (e.g. Thierfelder and Wall, 2009; Rockström et al., 2009) suggest that CA systems have a higher adaptability to climate change because of the higher effective rainfall due to higher water infiltration and therefore minimum surface water run-off as well as greater soil moisture-holding capacity. Through their effects on soil water conservation, CA systems can reduce crop yield variations and productive risk making the crop production system more reliable. As such, CA systems may make farmers less vulnerable to climate change.

Crop growth simulation models that integrate the impact of variable weather with a range of soil and crop management practices are widely used to explore potential impacts of climate change on future crop productivity and to examine options for adaptation by local stakeholders. The use of such models, with long runs (30 years or more) of daily climatic data thus provides a quicker and much less costly way of assessment compared to the traditional multi-location, multi-seasonal and multi-factorial field trials (Cooper et al., 2008). As an example, the crop growth model DSSAT (www.dssat.net) was used to predict water-limited maize grain yield for a site nearby Harare in Zimbabwe under 4 weather scenarios (including the baseline climate) and for the 2 tillage treatments (conventional tillage versus no-tillage CA) (Corbeels, unpublished results). For the baseline scenario (BS) simulated maize grain yield was on average about 720 kg ha^{-1} higher under CA compared to CT (Table 1). This was mainly due to increased water availability as a result of decreased water runoff under no-tillage. Predicted yields varied broadly, from a minimum of 1003 kg ha^{-1} to a maximum of 6483 kg ha^{-1} depending on seasonal rainfall amount and distribution. As expected, average grain yields for both tillage practices were lower for future climate scenarios with less and more variable rainfall (Table 1). The cumulative distribution functions of simulated maize grain yield are presented in Figure 2. Under the current climate the probability of producing at least 3000 kg ha^{-1} grains is 41 and 67 % for respectively CT and CA. Under future climate, due to water stress the probability drops to respectively 15 and 43%. The results indicate that the negative impact of climate change can be mitigated by adopting CA in the 'normal' years, but with a higher risk of lower yields in the 'good' and 'bad' years.

Table 1: Effect of climate change on maize yield (kg ha^{-1}) as simulated with the DSSAT crop growth model under conventional tillage (CT) and CA for the Henderson site nearby Harare, Zimbabwe. Variation coefficients in parenthesis.

	BS	RS	DS	RDS
CT	3107 (0.39)	2607 (0.35)	2577 (0.41)	2254 (0.43)°
CA	3830 (0.35)	3166 (0.34)	3328 (0.37)	2832 (0.40)

BS: base line weather scenario; RS: a 15% decrease in annual rainfall; DS: a 15% increase in the duration of dry spells; RDS:a combined 15% decrease in annual rainfall and 15% increase in the duration of dry spells

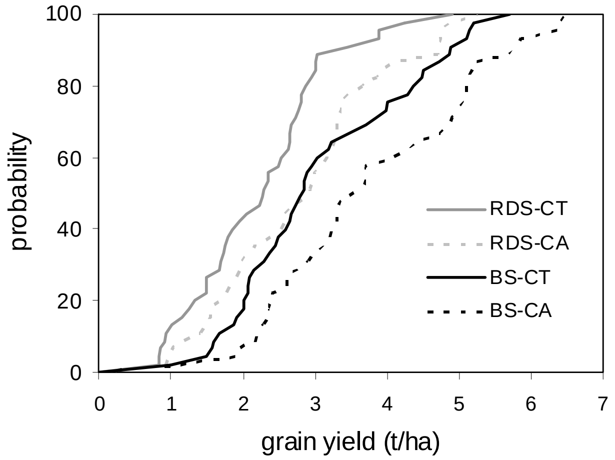

Figure 2. Cumulative probability functions of maize grain yield as simulated with the crop growth model DSSAT for climate scenario under CT and CA practices for the Henderson site nearby Harare, Zimbabwe. BS: base line weather scenario; RDS: weather scenario with a combined 15% decrease in annual rainfall and 15% increase in the duration of dry spells.

CONCLUSIONS

The design and implementation of new innovative cropping systems that secure a sustainable use of land are fundamental for achieving increased world food production with greater protection of the environment. Increased soil carbon and nutrient use efficiency with improved biodiversity are critical attributes of these sustainable cropping systems that become at the same time more resilient and make farmers less vulnerable to future changes in climate. Conservation agriculture, in particular when combined with spatial and annual crop diversification, shows high potential as a sustainable land use practice. The main challenges ahead with CA are integrated pest control based on natural processes that replaces the high dependency of mechanized farms on pesticide use, and the adaptation of the CA systems to the local conditions of resource-poor farmers in Africa and elsewhere.

REFERENCES

Altieri, M.A. (2002) 'Agroecology: the science of natural resource management for poor farmers in marginal environments', Agriculture, *Ecosystems and Environment*, 93, 1–24.

Baldé, A.B., Scopel, E., Affholder, F., Corbeels, M., Da Silva, F.A.M., Xavier, J.H.V., Wery, J. (2011) 'Agronomic performance of no-tillage relay intercropping with maize under smallholder conditions in Central Brazil', *Field Crops Research*, 124, 240-251.

Batlle-Bayer, L., Batjes, N.H., Bindraban, P.S. (2010) 'Changes in organic carbon stocks upon land use conversion in the Brazilian Cerrado: A review', *Agriculture, Ecosystems and Environment,* 137, 47-58.

Cassman , K.G. (1999) 'Ecological intensification of cereal production systems: yield potential, soil quality and precision agriculture', *Proceedings of the National Academy of Sciences,* 96, 5952-5959.

Cassman, K.G., Dobermann, A. and Walters, D.T. (2002) 'Agroecosystems, nitrogen_use efficiency, and nitrogen management', *Ambio,* 31, 132-140.

Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferaw, B., and Twomlow, S. (2008) 'Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change?', *Agriculture, Ecosystems and Environment,* 126, 24-35.

Corbeels, M., O'Connell, A.M., Grove, T.S., Mendham, D.S. and Rance, S.J. (2003) 'Nitrogen release from legume and eucalypt residues as affected by their biochemical quality and degree of contact with soil', *Plant and Soil*, 250, 15-28

Corbeels, M., Scopel, E., Cardoso, A., Bernoux, M., Douzet, J.M. and Siqueira Neto, M. (2006) 'Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil', *Global Change Biology*, 12, 1773-1787.

Cowie, A.L., Penman, T.D., Gorissen, L., Winslow, M.D., Lehmann, J., Tyrrell, T.D., Twomlow, S., Wilkes, A., Lal, R., Jones, J.W., Paulsch, A., Kellner, K. and Akhtar-Schuster, M. (2011) 'Towards sustainable land management in the drylands: Scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity', *Land Degradation & Development,* 22(2), 248-260.

Garrity, D., Akinnifesi, F., Ajayi, O., Sileshi G. W., Mowo, J.G., Kalinganire, A.,Larwanou, M and Bayala, J. (2010) 'Evergreen Agriculture: a robust approach to sustainable food security in Africa', *Food Security*, 2(3), 197-214.

Giller, K., Witter, E., Corbeels, M. and Tittonell, P. (2009) 'Conservation agriculture and smallholder farming in Africa: The heretics' view', *Field Crops Research,* 114, 23-34.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J. and Dendooven, L. (2009) 'Conservation agriculture and soil carbon sequestration: between myth and farmer reality', *Criica. Reviews in Plant Sciences,* 28, 97–122.

Hobbs, P.R. (2007). 'Conservation agriculture: what is it and why is it important for future sustainable food production?', *Journal of Agricultural Science,* 145, 127-137.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setala, H., Symstad, A.J., Vandermeer, J.J. and Wardle, D.A. (2005) 'Effects of biodiversity on ecosystem functioning: a consensus of current knowledge', *Ecological Monographs*, 75(1), 3–35.

Kapkiyai, J.J., Karanja, N.K., Qureshi, J.N., Smithson, P.C. and Woomer, P.L. (1999) 'Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management', *Soil Biology and Biochemestry*, 31, 1773–1782.

Kassam, A.H., Friedrich, T., Shaxson, F. and Pretty, J. (2009) 'The spread of conservation agriculture: Justification, sustainability and uptake', *International Journal of Agriculture Sustainability*, 7, 292–320.

Keating, B.A., Carberry, P.S., Bindraban, P., Asseng, S., Meinke, H. and Dixon, J. (2010) 'Eco-efficient agriculture: concepts, challenges and opportunities', *Crop Science*, 50, 109-119.

Kladivko, E.J. (2001) 'Tillage systems and soil ecology', *Soil and Tillage Research,* 61, 61–76.

Lal, R. (2004) 'Soil carbon sequestration impacts on global climate change and food security', *Science,* 403, 1623–1627.

Lal, R. (2010) 'Enhancing eco-efficiency in agroecosystems through soil carbon sequestration', *Crop Science,* 50, 30-40.

Lavelle, P., Decaens, T., Aubert, M., Barota, S., Blouin, M., Bureau, F., Margerie, P., Mora, P. and Rossic, J-P. (2006) 'Soil invertebrates and ecosystem services', *European Journal of Soil Biology,* 42, 3–15.

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J-P., Hector, A., Hooper, U., Huston, M.A., Raffaelli, D., Schmid, B., Tilman, D. and Wardle, D.A. (2001) 'Biodiversity and ecosystem functioning: current knowledge and future challenges', *Science,* 294, 804–808

Malézieux ,E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine H., Rapidel, B., de Tourdonnet, S. and Valantin-Morison, M. (2009) 'Mixing plant species in cropping systems: concepts, tools and models. A review', *Agronomy for Sustainable Development*, 291, 43-62.

Maltas, A., Corbeels, M., Scopel, E., Oliver, R., Douzet, J.M., Da Silva, F. A. M. and Wery, J. (2007)' Long-term effects of continuous direct seeding mulch-based cropping systems on soil nitrogen supply in the Cerrado region of Brazil', *Plant and Soil*, 298, 161-173.

Matson, P., Parton, W., Power, A. and Swift, M. (1997) 'Agricultural intensification and ecosystem properties', *Science,* 277, 504–509.

Nielsen, U.N., Ayres, E., Wall, D.H. and Bardgett, R.D. (2011) 'Soil biodiversity and carbon cycling: a synthesis of studies examining diversity-function relationships', *European Journal of Soil Science,* 62, 105-116.

Pretty, J. (2008) 'Agricultural sustainability: concepts, principles and evidence', Philosophical *Transactions of the Royal Society Biological Science,* 363, 447–465.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. and Damgaard-Larsen, S. (2009) 'Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research', *Soil and Tillage Research,* 103, 23–32.

Rusinamhodzi, L., Corbeels, M., van Wijk, M., Rufino, M.C., Nyamangara, J. and Giller K.E. (2011) 'Long-term effects of conservation agriculture practices on maize yields under rain-fed conditions: lessons for southern Africa', *Agronomy for Sustainable Development,* 31, 657-673.

Scopel, E., Findeling, A., Chavez Guerra, E. and Corbeels, M. (2005) 'The impact of direct sowing mulch-based cropping systems on soil erosion and C stocks in semi-arid zones of western Mexico', *Agronomy for Sustainable Development,* 25, 425-432.

Scopel, E., Macena, F., Corbeels, M., Affholder, F. and Maraux, F. (2004) 'Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions', *Agronomie,* 24,1-13.

Silver, W.L, Brown ,S. and Lugo, A.E. (1996) 'Effects of changes in biodiversity on ecosystem function in tropical forests', *Conservation Biology,* 10(1),17–24.

Thierfelder, C. and Wall, P.C. (2010) 'Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change', *Journal of Crop Improvement,* 24, 113–121.

Tilman, D. and Downing, J.A. (1994) 'Biodiversity and stability in grasslands', *Nature,* 367, 363–365.

Van Ittersum, M.K. (2011) 'Future harvest: the fine line between myopia and utopia', Wageningen University, Netherlands, 32pp.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R. and Six, J. (2011) 'Agronomic use efficiency of N fertilizer in maize-based systems in Sub-Saharan Africa within the context of Integrated Soil Fertility Management', *Plant and Soil*, 339,35-50.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K., Smaling, E., Woomer, P.L. and Sanginga, N. (2010) 'Integrated soil fertility management: Operational definition and consequences for implementation and dissemination', *Outlook on Agriculture,* 39, 17–24.

Van Noordwijk, M. and Ong, C.K. (1999) 'Can the ecosystem mimic hypotheses be applied to farms in African Savannahs?', *Agroforestry Systems*, 45, 131–158.

Walker, B., Sayer, J., Andrew, N.L. and Campbell, B. (2010) 'Should enhanced resilience be an objective of natural resource management research for developing countries science?' *Crop Science,* 50, S-10-S-19.

Way, M.J. and Emden H.F. (2000) 'Integrated pest management in practice – pathways towards successful application', *Crop Protection,* 19, 81-103.

Zingore, S., Manyame, C., Nyamugafata, P. and Giller, K.E. (2005) 'Long-term changes in organic matter of woodland soils cleared for arable cropping in Zimbabwe', *European Journal of Soil Science,* 57, 727–736.