academicJournals

Vol. 6(9), pp. 241-248, September, 2015
DOI 10.5897/JSSEM15.0508
Articles Number: 0E26F4154882
ISSN 2141-2391

http://www.academicjournals.org/JSSEM

Journal of Soil Science and Environmental Management

Full Length Research Paper

Applicability of conservation agriculture for climate change adaptation in Rwanda's situation

M. Kabirigi[1]*, B. Musana[1], F. Ngetich[2], J. Mugwe[2], A. Mukuralinda[3] and N. L. Nabahungu[4]

[1]Research Unit of Natural Resources Management, Rwanda Agriculture Board (RAB), Kigali, Rwanda.
[2]Department of agricultural resources management, Kenyatta University (KU), Nairobi, Kenya.
[3]International Council for Research in Agroforestry (ICRAF), Rwanda.
[4]International Institute of Tropical Agriculture (IITA), Bukavu, Democratic Republic of the Congo.

Received 13 June, 2015; Accepted 27 July, 2015

Improving food security and environmental conservation should be the main targets of innovative farming systems. Conservation agriculture (CA), based on minimum tillage, crop residue retention and crop rotations has been proposed against poor agricultural productivity and soil degradation. This paper discusses the applicability and potential benefits of CA in Rwanda under the unfolding climate change scenario. The potential and benefits from CA may vary with rainfall regime. In high rainfall areas (For example North and West of Rwanda), the soils are susceptible to soil erosion and face fertility decline while in low rainfall areas (For example East of Rwanda) crops fail due to sub-optimal water use efficiency. Furthermore, low organic carbon content lower fertilisers response and government targets of increasing production through Crop Intensification Program, is limited. It has been shown that CA can: Reduce soil loss from 35.5 to 14.5 t/ha/year, have 50-70% greater infiltration and increase 42% of organic carbon. Long term analysis using Agricultural Production System Simulator showed that CA can increase yield from 3.6 to 4.4t/ha in areas having >770 mm. Based on the evidence from regional research, CA has a good potential for climate change adaptation in both high and low rainfall areas of Rwanda. However, decreased yield observed in high rainfall areas, increased labour requirements when herbicides are not used and lack of mulch due to priority given to feeding of livestock constrained CA adoption. We conclude that there is a need for critical assessment under which ecological and socio economic conditions CA is suited for smallholder farming in Rwanda.

Key words: Conservation agriculture, climate change, Rwanda.

INTRODUCTION

In Rwanda, besides agriculture's contribution to GDP (31%), is the main employer sector, especially of the poorer and less educated segments of the population, account for 70% of export revenues and 90% of national food needs (Cantore, 2011a). Attempts to increase agricultural production and food consumption are destabilized by rapid population growth (Boserup, 2005). Consequently, crop productivity is declining (Kelly et al., 2001; Cantore, 2011b) as a result of intensive farming, which leads to soil loss through erosion and declining soil fertility (Kagabo et al., 2013). Whereas, Crop Intensification Program (CIP) policy in Rwanda, aiming at

*Corresponding author. E-mail: kabirimi@yahoo.fr

boosting agricultural productivity through an improvement of productive inputs use, irrigation and rainwater use efficiency and soil quality (Cantore, 2011a) started in 2007, expected potential increase in production has not been attained probably due to low soil organic matter content, low fertilizer response and rainfall variability.

Climate variability is expected to unfavorably affect agricultural production in Africa (Bryan et al., 2013). Concerns that climate variability will have an adverse impact on the livelihoods of the rural poor in developing countries have been raised (Below et al., 2010). Due to heavy dependence on rainfed agriculture (Lybbert and Sumner, 2012), the effects of climate variability are expected to be particularly prominent (Lybbert and Sumner, 2012). For example, in drought prone areas like Eastern part of Rwanda, frequent droughts lead to significant reduction in crop yields while delayed onset of rains is reported to affect the timing of farm operations (e.g. opening up of seedbeds, beginning of planting) which shortens the crop growing season and hence resulting into poor crop yields (Rwanyiziri and Rugema, 2013).

Furthermore, it was demonstrated that in the dry Mediterranean areas, severe natural resource constraints, such as soil erosion through high intensity rain falling on bare soil, poor soil fertility as a result of low soil organic matter contents in agricultural soils as well as water scarcity in the summer season severely threaten the eco-logical, agronomic and economic sustainability of farming (Kassan et al., 2012).

Conservation agriculture (CA), consisting of disturbing the soil as little as possible, keeping the soil covered, and mixing and rotating crops, has been discussed to be a potential remedy to soil degradation (Knowler and Bradshaw, 2007; Giller et al., 2011; Rusinamhodzi et al., 2011; Bayala et al., 2012). In addition, based on the evidence from regional research, CA is recommended for climate variability adaptation in both high and low rainfall areas (Below et al., 2010; Hobbs and Govaerts, 2010). In high rainfall areas (For example Northern and western part of Rwanda), the soils are susceptible to soil erosion and experience fertility decline (Kagabo et al., 2013) while in low rainfall areas (East) crops fail due to water related stresses (Verdoodt and Van Ranst, 2003).

The increase in soil moisture as a result of CA application has a potential of enabling crops to surmount seasonal dry spells, mitigate the effects of drought and rainfall variability and reduce the risk of crop failure (Thierfelder and Wall, 2010). CA has significant potential to improve rainfall-use efficiency through increased water infiltration and decreased evaporation from the soil surface, with associated decreases in runoff and soil erosion (Thierfelder and Wall, 2009). However, decreased yield observed in high rainfall areas, increased labor requirements when herbicides are not used and lack of mulch due to priority given to feeding of livestock constrains its adoption (Giller et al., 2009). Several researchers conclude that, CA is a system approach to sustainable agriculture (Chivenge et al., 2007; Govaerts et al., 2009; Mkoga et al., 2010; Li et al., 2011; Mrabet et al., 2012). There is still limited information on how CA techniques can best be targeted for desired impact in high and low rainfall areas of Rwanda for this reason there is need to assess potential benefits of CA in Rwanda for both high and low rainfall areas.

Rwanda, brief description

Rwanda is a land-locked country covering an area of 26,338 km^2 and is located between latitudes 1°04' and 2°51' South and longitudes 28°45' and 31°15' East (Verdoodt and Van Ranst, 2003). Rwanda's topography is considered hilly and mountainous with altitude ranging between 900 and 4,507 m above sea level (average of 1700 m) (Kagabo, 2013; Ndayisaba, 2014; Nduwumuremyi, 2014). However, the eastern part of the country is relatively flat with altitude well below 1500 m (Ndayisaba, 2014). Despite its equatorial location in the Great Lakes region in central-east Africa, the country enjoys a tropical temperate climate with diverse ecosystems (REMA, 2011). The diversity in climatic conditions allows an important diversification from crops suited for tropical areas to crops adapted to temperate climatic conditions (Verdoodt and Van Ranst, 2003). The average temperature for Rwanda is around 20°C and varies with the topography. Annual rainfall varies with altitude and ranges from 700 to 2,500 mm (Figure 1). The country experiences two rainy seasons in a year associated with the North-South oscillating migration of the Inter- Tropical Convergence Zone (ITCZ) (Safari, 2012).

The agricultural year in Rwanda has three seasons namely agricultural Season A which starts in September of one calendar year and ends in February of the following calendar year; Agricultural Season B which starts in March and ends in July of the same calendar year; and Agricultural Season C which starts in August and ends with September of the same calendar year. The seasons can sometimes be subject to climate uncertainties and present some differences from one Province to another. In Rwanda, farmers growing crops in pure stand represent 37.6 and 62.4% practice mixed stand (NISR, 2013).

METHODOLOGY

This study is a review and information included was gathered in different documents which were chosen in a systematic way. The idea was to document the effect of CA for climate change adaptation in both high rainfall area and low rainfall area of Rwanda. The first priority was given to a scientifically peer reviewed source of information (Peer reviewed papers). The second priority was given to the year of publication and thus recently published papers were highly considered. The third priority was given to the paper's response to the issues related to climate change (Drought, flood and water logging issues). Lastly the paper was selected in accordance to the topic of discussion for example soil fertility

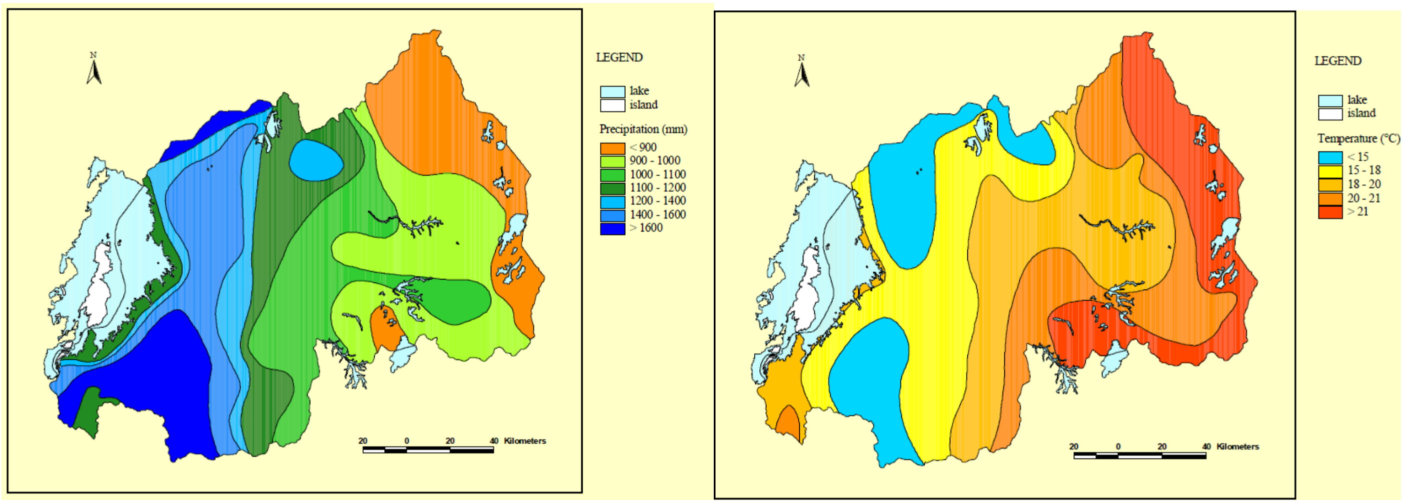

Figure 1. Rainfall and temperature distribution in Rwanda. Source: Verdoodt and Van Ranst (2003).

improvement, water use efficiency, trade-offs of implementing CA.

MAIN FINDINGS

Conservation agriculture: An overview

Conservation agriculture originated in the USA in the 1950s and from then until 2007 the USA had the largest area under no-till worldwide (Kassam et al., 2009) while Asian and African countries have begun to take up CA practices only in the last 10-15 years (Friedrich et al., 2009). As defined by Friedrich et al. (2009), CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. Hobbs and Govaerts (2010) highlighted CA as a Climate Change Adaptation Strategy where improved soil quality and improved nutrient cycling will improve the resilience of crops to adapt to changes in local climate change. Several researchers concluded that CA is a system approach to sustainable agriculture in Latin America, Asia and Africa (Chivenge et al., 2007; Govaerts et al., 2009; Mkoga et al., 2010; Li et al., 2011; Mrabet et al., 2012). There is increasing awareness all over the world of the negative effects of conventional agriculture and the need to change traditional agricultural practices (Baker et al., 2007; Morris et al., 2010). The key problem of conventional agriculture faces, especially in the tropics, is the steady decline in soil fertility, which is closely correlated to the duration of soil use (Clay et al., 1996; Singh and Malhi, 2006). This is primarily due to soil erosion and the loss of organic matter associated with conventional tillage practices (Chivenge et al., 2007), which leave the soil bare and unprotected in times of heavy rainfall, wind and heat (Derpsch, 2003). Thus, Zero-tillage was born out of a necessity to combat soil degradation and has been widely adopted by farmers at different scale (Kassam et al., 2009).

Environmental implications of conventionnel versus conservation agriculture

Conventional tillage has been asserted to lead to land degradation resulting from common, but exploitative, farming practices such as ploughing that destroys the soil structure and degrades organic matter, burning or removing crop residues, monocropping among others (Rusinamhodzi et al., 2011). This, in addition to the emissions from the farm equipment itself, increases carbon dioxide levels in the atmosphere (Chivenge et al., 2007). By eliminating tillage, crop residues decompose where they lie, and cover crops, carbon loss can be slowed and eventually reversed (Baker et al., 2007). According to Hobbs and Govaerts (2010) agriculture contributes significantly to greenhouse gas (GHG) emissions: CO_2, CH_4 and N_2O for that reason promoting agricultural practices that mitigate climate change by reducing GHG emissions is important. In addition to keeping carbon in the soil, no-till farming reduces nitrous oxide (N_2O) emissions, depending on rotation (Hobbs and Govaerts, 2010). Nitrous oxide is a potent greenhouse gas that stays in the atmosphere for 120 years. According to Govaerts et al. (2009), no-till has carbon sequestration potential through storage of soil organic matter in the soil of crop fields (Hobbs and Govaerts, 2010). By the same author, cropland soils are ideal for use as a carbon sink, since they have been depleted of carbon in most areas. It is estimated that enormous carbon that was trapped in the soil has been released because of tillage (Håkansson, 1994; Balesdent et al., 2000; Six et al., 2004). Conventional farming practices that rely on tillage have removed carbon from the soil ecosystem by removing crop residues such as left over corn stalks, and through the addition of chemical fertilisers which have negative effects on soil microbes (Baker et al., 2007). CA gives farmers a means of conserving, improving and making more efficient use of their natural resources. CA is also key to managing agricultural resources for biodiversity preservation as far as agricultural practices have impact on a wide range of ecosystem services, including water quality, pollination, nutrient cycling, soil retention, carbon sequestration, and biodiversity conservation. In turn, ecosystem services affect agricultural productivity (Varela 2001, Tscharntke et al. 2005).

Soil quality improvement by conservation agriculture

Soil organic matter (SOM) is an important determinant of soil fertility, productivity and sustainability, and is a useful indicator of soil quality in tropical (Chivenge et al., 2007). Residue retention and reduced tillage are both CA management options that may enhance soil organic carbon (SOC) stabilization in tropical soils (Chivenge et al., 2007). In extremely degraded soils there is low recycling of nutrients during the decomposition of organic matter, and low biological activity (small quantity of microorganisms). CA aims to address the problems of soil degradation resulting from agricultural practices that deplete the organic matter and nutrient content of the soil (Giller et al., 2009). No-till improves soil quality (soil function), carbon, organic matter, aggregates, protecting the soil from erosion, evaporation of water, and structural breakdown (Araya et al., 2012). A reduction in tillage passes helps prevent the compaction of soil. Recently, researchers found that no-till farming makes soil much more stable than ploughed soil (Li et al., 2011). In addition, No-till stores more carbon in the soil and carbon in the form of organic matter is a key factor in holding soil particles together. Crop residues left intact help both natural precipitation and irrigation water infiltrate the soil where it can be used (Friedrich et al., 2009). The crop residue left on the soil surface also limits evaporation, conserving water for plant growth (Thierfelder and Wall, 2009). Soil compaction and no tillage-pan, soil absorbs more water and plants are able to grow their roots deeper into the soil and suck up more water.

Desired effect of conservation agriculture for climate change adaptation and mitigation

Agricultural production, including access to food in many African countries, is projected to become severely compromised by climate change (Below et al., 2010). This arises from the fact that African agriculture is mainly rain-fed, and the areas suitable for agriculture, the length of growing seasons and yield potential, particularly along the arid and semi arid areas, are all expected to decrease. Therefore, adaptation is a key factor that will shape the future severity of climate change impacts on food production (Lobell et al., 2008). Benefits of CA systems to climate change adaptation and mitigation have been widely published (Govaerts et al., 2009; Kassam et al., 2009; Thierfelder and Wall, 2009, 2010; Li et al., 2011; Lanckriet et al., 2012). These benefits include less erosion possibilities, better water conservation, improvement in air quality due to less emission being produced, and a chance for larger biodiversity in a given area. Producers will find that the benefits of CA will come later rather than sooner (Chivenge et al., 2007; Thierfelder and Wall, 2009) since CA takes time to build up enough organic matter and have soils become their own fertiliser, the process does not start to work over night. But if producers make it through the first few years of production, results will start to become more satisfactory. Improved soil quality and improved nutrient cycling with CA will improve the resilience of crops to adapt to changes in local climate change while drought tolerance can be increased in some areas with CA (Hobbs and Govaerts, 2010). Thierfelder and Wall (2009) concluded that CA benefits more in areas where soil moisture is a limiting factor like in Bugesera district (Eastern Rwanda).

Gender implications in conservation agriculture

Effective application of agricultural technologies in production has strategic gender implications (Lubwama, 1999). Although men and women work together in agricultural activities, there is always some form of gender-based division of labour (Ajani, 2009). Most laborious activities, such as ploughing are jointly done by men and women while other operations (sowing, weeding, manuring and stacking) are mainly done by women. The productivity of labour will be altered depending on accessibility of the technology between men and women (Lubwama, 1999). Since gender and socio-economic issues cut across all areas of concern in agricultural production, there is a need to know how development policies and programs are likely to affect the economic activities and social relationships among different groups of people in a community (Lubwama, 1999). Women play a critical role in agriculture (Motzafi-Haller, 2005), bearing most responsibility for water, and contribute to household well-being through their income generating activities. Yet, women usually have limited access to resources and opportunities and their productivity remains low relative to their potential (Ajani, 2009). It has been proved that, rural women work almost all the time without rest except for some hours of sleep, women take part in all forms of activity whereas men do not do certain types of work reserved for women by nature or by tradition. CA proved the potential to address the problem of intensive labour requirements in smallholder farmers (Bishop-Sambrook et al., 2004; Giller et al., 2009) as a result it reduces and spreads women's workload over time and reduces women's burden on fetching water. It enables early planting of crops: makes women less dependent on oxen or mechanical tillage equipment, increases crop productivity and production of different crops, and increases production of food-security crops. Women farmers maintain that their work within agriculture has become more planned and systematic (including planting, use of fertiliser and crop rotation). Women manage to improve the welfare of their families because of CA as a result of increased production (Lubwama, 1999).

Conservation agriculture for improved agricultural water productivity

The majority of the world's rural poor people depend on rain fed crop and livestock systems for their food and incomes (Wallace, 2000). Rain-fed agriculture will continue to play a critical role in future food needs which is increasing according to the population pressure particularly in Africa (Rockström et al., 2003; Rockström et al., 2010). However, rain fed agriculture in semi-arid and arid regions is highly variable and unpredictable due to erratic rainfall, structurally unstable soils leading to low overall productivity (Jat et al., 2012). Increasing WP is particularly appropriate where water is scarce and it is very important for increasing the productivity and sustainability of rain fed cropping systems of poor smallholder farmers (Sidhu, 2014). However, rainfall variability coupled with dry spells and droughts in between have been identified as main factor to lower yield and rainwater productivity in many rain-fed environments (Howden et al., 2007). Furthermore rainfall variability and the frequency of extreme events are likely to increase in the future as a result of climate change (Cooper et al., 2009). In addition conventional farming system based on soil inversion using plough and hoe, contributes to soil erosion and soil desiccation thus reduce water productivity (Rockström et al., 2003). Fortunately, there is high potential to increase land and water productivity in smallholder rain-fed crop with CA (Su et al., 2007). Conservation farming based on non-inversion tillage systems from zero-tillage to reduced tillage have been recommended maximizing soil infiltration and reducing soil erosion while conserving energy and labor (Su et al., 2007). Moreover mulch cover provides benefits in improved water infiltration and reduced soil surface evaporation especially under dry or moisture-limited conditions (Turmel et al., 2014).

Concerns and trade-offs of implementing CA

At farm and village levels, trade-offs in the allocation of resources become important in determining how CA may fit into a given farming system (Giller et al., 2011). There are many reasons why CA cannot always be a win-win situation. Since CA is based upon establishing an organic layer and producing its own fertiliser, then this may take time to produce that layer (Thierfelder and Wall, 2009). It can be many years before a producer will start to see better yields than he/she has had previously before. Another financial undertaking is purchasing of new equipment. When starting CA a producer may have to buy new planters or drills in order to produce effectively, also comes the responsibility of harvesting a crop. These financial tasks are ones that may impact whether or not a producer would want to conserve or not. With CA comes the idea of producing enough food (Hobbs and Govaerts, 2010), with cutting back in fertiliser, not tilling of ground and among other processes comes the responsibility to feed the world. With this increase comes the responsibility for producers to increase food supply with the same or even less amounts of land to do it on. With CA problems arise in the fact that if farms do not produce as much as conventional ways, then this leaves the world with less food for more people. While benefits of CA are most directly attributed to the mulch of crop residues retained in the field, limited availability of crop residues is under many farming conditions because of priority given to livestock feeding, used as fuel and as construction materials (Giller et al., 2009)

DISCUSSION AND POLICY IMPLICATIONS

Improving agricultural production and environmental conservation is, among others, the target of government of Rwanda in order to provide sustainable food security for ever increasing population. To achieve this objective Rwanda have started, since 2007, crop intensification program aiming at boosting agricultural productivity through an improvement of productive inputs use, irrigation and rainwater use efficiency and soil quality (Cantore, 2011a). However, the expected potential increase in yield has not been attained as a result from low soil organic matter content, low fertilisers response and rainfall variability. Several studies showed that the climate change and variability is occurring in Rwanda in various forms. For example, dry spells occurring in drought prone areas, floods in high rainfall areas and delayed onset or early cessation of rainfall. Considering topographic variability of Rwanda which correlates with rainfall pattern, climate variability and change is expected to continue to compromise agricultural production if no proper adaptation and/or mitigation strategies are put in place. Tillage is claimed to be one of main source greenhouse gas (GHG) emitted in the atmosphere resulting in climate change which, in turn, affect negatively agricultural production (Six et al., 2004) thus promoting agricultural practices that mitigate climate change by reducing GHG emissions is important (Hobbs and Govaerts, 2010). In Rwanda land preparation is practiced mostly by manual labour, using hand hoe with thorough grass clearing to facilitate seedbed preparation and planting. The cut biomass and residues are disposed of by burning in situ or transported for other purposes such as using them as fuel wood, used as construction materials, etc. Tillage is performed in two sessions, namely first and second tillage and most of crops grown require tilled depth from 20 to 60 cm. In Rwanda mechanized tillage is being promoted as labour- and time-saving technology consisting of the mechanical soil manipulation of an entire field, by ploughing followed by one or more harrowings. The degree of soil disturbance depends on the type of implement used, the number of passes, soil and intended crop type. However as far as conservation agriculturists are concerned, mechanized tillage as well result in soil physical, chemical and biological disturbance leading to land degradation (Acharya and Sharma, 1994; Singh and Malhi, 2006; Morris et al., 2010). Conservation tillage is evolving practice to reduce the risk of soil erosion, conserve soil organic matter and improve soil structural stability (Morris et al., 2010). In Rwanda there have been forms of CA but they are not yet documented. For example in Nyagatare district farmers sow maize under minimal tilled land (Tilled once) and beans are sown with the first weeding operations, cowpeas are sown with first tillage and no weeding done throughout the growth till harvesting and agroforestry trees have been promoted to be grown on contour lines. Conservation tillage systems to protect the soil and water reserves often have limited appeal to producers unless they offer economic advantages. Conservation practices also have to improve farmer production and income and buffer the production system against changes in climate. Mkoga et al. (2010) extrapolated CA and observed significant increase in yield from 3.6 to 4.4 t/ha in CA practices, however Mupangwa and Jewitt (2011) found no difference in maize yield in both conservation tillage and conventional tillage. This contradiction can be attributed to site particuarities and raise a concern how adoption of CA in Rwanda particularly can result in increased yield. CA has been promoted and practiced as solution for agricultural sustainability problems resulting from soil erosion and fertility decline (Bram Govaerts et al., 2009) and reduce farmers' vulnerability to drought, and address low draught power ownership levels (Mashingaidze et al., 2012). Studies on long-term impact of CA in Zimbabwe shown that the practices result in increased organic carbon but differently according soil size (texture) (Chivenge et al., 2007). According to Chivenge et al. (2007) the increase in soil organic matter with residue retention is higher on sandy soils than clay soils while reduction in soil organic matter with tillage is higher on clay soils thank on sandy soils. From this point of view, In Rwanda residues retention can be recommended on hillsides and reduced tillage recommended in wetlands. CA has shown potential benefit for both high rainfall areas and low rainfall areas (Mkoga et al., 2010). CA results in improved soil physical and biological health, better nutrient cycling and crop growth as well as increasing water infiltration (Ranging from 45 to 87% increase in infiltration rate with CA compared to conventional practices) and soil penetration by roots, which allows crops to better adapt to lower rainfall and make better use of water (Thierfelder and Wall, 2009; Hobbs and Govaerts, 2010). Water and wind erosion are also reduced by CA since the soil surface is protected and water runoff is lowered as more water enters the soil profile. Nevertheless, Mupangwa and Jewitt (2011) have observed water losses through evaporation in both tilled and non tilled land. In Rwanda, despite potential benefit on environmental preservation, adoption of CA would face multiple tradeoffs. CA require a long time planning and commitment to resources protection while agriculture in Rwanda is still of subsistence thus to adopt CA require alternative source of food while waiting for the increased yield as results of effect of CA. From this point of view, it is of great importance to research to translate CA into field practices attractive to farmers. Smallholder rainfed crop production in semi-arid areas is characterized by low residue production levels (Mashingaidze et al., 2012). Smallholder crop–livestock systems face tradeoffs among various options for crop residue use (Valbuena et al., 2012). In Rwanda, there is household dependence on crop residues for other purposes rather using them for mulching, such as fuelwood, livestock feed, fencing houses. Crop and livestock are integral components of most smallholder livelihoods and therefore, technologies and approaches need to include both crops and livestock to better sustain agricultural production (Valbuena et al., 2012). Policy of zero grazing Rwanda has been adopted these last years and may present both challenges and opportunities as far as CA is concerned. The approach reduces livestock pressure on grasses but at the same time require much more use of crop residues as animal feeds. The lack of adoption of CA in many countries has been attributed to farmers conservative mindset (Sanginga and Woomer, 2009) but as mentioned earlier, farmers are most interested in agricultural technologies that can directly increase yield for food security. In addition, weed control in CA is a greater challenge than in conventional agriculture because there is no weed seed burial by tillage operations and soil-applied herbicides are not incorporated, resulting in reduced efficacy (Chauhan et al., 2012). Weed issues increase farmers' dependence on herbicides yet smallholder farmers in Rwanda have limited access to the necessary inputs and equipment and Rwanda's policy does not allow the use of herbicides. It is of great importance that nowadays research should focus on development of seeds with high vigour and improved canopy architecture of crop cultivars and low-cost and high-efficiency herbicide application technologies. CA has been, as well, reported as a complex and require intensive community based extension thus adoption rates have been low (Li et al., 2011). To promote CA in Rwanda requires increasing awareness to farmers with stronger and wider demonstrations.

Conclusion

This paper reviewed information about benefit and concerns about CA and discussed its applicability in Rwanda under already happening climate change scenario. Studies have shown that climate change is occurring in Rwanda in forms of prolonged and more frequent droughts, unexpected less and early cessation of rains, high run-off that causes soil erosion and destroys water retention ditches and destruction of crops like bananas by violet winds accompanied by heavy rain-storms. CA has been reported to have a good potential for climate change adaptation in both high and low rainfall areas of Rwanda. However, decreased yield observed in high rainfall areas, increased labor requirements when herbicides are not used and lack of mulch due to poor productivity and priority given to using them for other purposes constrained CA adoption. There is a need for critical assessment under which ecological and socio economic conditions CA is suited for smallholder farming in Rwanda. It is required to research to translate CA into field practices attractive to farmers as well as focus on development of seeds with high vigour and improved canopy architecture of crop cultivars and low-cost and high-efficiency herbicide application technologies.

Conflict of Interest

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENTS

This work was made possible with assistance from Sustainable Intensification of Maize Legumes cropping systems for food security in Eastern and Southern Africa (SIMLESA) project.

REFERENCES

Acharya CL, Sharma PD (1994). Tillage and mulch effects on soil physical environment, root growth, nutrient uptake and yield of maize and wheat on an Alfisol in north-west India. Soil Till. Res. 32(4):291-302.

Ajani OIY (2009). Gender dimensions of agriculture, poverty, nutrition and food security in Nigeria, International Food Policy Research Institute (IFPRI).

Araya T, Cornelis WM, Nyssen J, Govaerts B, Getnet F, Bauer H, Amare K, Raes D, Haile M, Deckers J (2012). Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. Field Crops Res. 132:53-62.

Baker JM, TE Ochsner, RT Venterea and TJ Griffis (2007). "Tillage and soil carbon sequestration—What do we really know?" Agric. Ecosyst. Environ. 118(1):1-5.

Balesdent J, Chenu C, Balabane M (2000). Relationship of soil organic matter dynamics to physical protection and tillage. Soil Till. Res. 53(3):215-230.

Below T, Artner A, Siebert R, Sieber S (2010). Micro-level practices to adapt to climate change for African small-scale farmers. A review of Selected Literature. Environ. Prod. Technol. Division 953.

Bishop-Sambrook C, Kienzle J, Mariki W, Owenya M, Ribeiro F (2004). "Conservation agriculture as a labour saving practice for vulnerable households." A study of the suitability of reduced tillage and cover crops for households under labour stress in Babati and Karatu districts, northern Tanzania. Rome: International Fund for Agricultural Development and Food and Agriculture Organization of the United Nations.

Boserup E (2005). The conditions of agricultural growth: The economics of agrarian change under population pressure, Transaction Publishers.

Bryan EC, Okoba B, Roncoli C, Silvestri S, Herrero M (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. J. Environ. Manag. 114:26-35.

Cantore N (2011). The crop intensification program in Rwanda: A sustainability analysis. Overseas Development Institute.[Available online]: http://dspace. cigilibrary. org/jspui/bitstream/123456789/31634/1/ODI-% 20The% 20Crop% 20Intensification% 20Program% 20in% 20Rwanda. pdf 1.

Chauhan BS, Singh RG, Mahajan G (2012). Ecology and management of weeds under conservation agriculture: A review. Crop Protection 38:57-65.

Chivenge P, Murwira H, Giller K, Mapfumo P, Six J (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: implications for conservation agriculture on contrasting soils. Soil Till. Res. 94(2):328-337.

Clay DC, Byiringiro FU, Kangasniemi J, Reardon T, Sibomana B, Uwamariya L, Tardif-Douglin D (1996). Promoting food security in Rwanda through sustainable agricultural productivity: Meeting the challenges of population pressure, land degradation, and poverty, Michigan State University, Department of Agricultural, Food, and Resource Economics.

Cooper K, Singh PC, Dimes J, Traore P, Rao K, Dixit P, Twomlow S (2009). "Farming with current and future climate risk: Advancing a'Hypothesis of Hope'for rainfed agriculture in the semi-arid tropics." J. SAT Agric. Res. 7:1-19.

Derpsch R (2003). Conservation tillage, no-tillage and related technologies. Conservation agriculture, Springer: pp. 181-190.

Friedrich T, Kassam A, Shaxson F (2009). Conservation agriculture. Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) Project. Karlsruhe, Germany: European Technology Assessment Group.

Giller KE, Corbeels M, Nyamangara J, Triomphe B, Affholder F, Scopel E, Tittonell P (2011). A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field crops research 124(3):468-472.

Giller KE, Witter E, Corbeels M, Tittonell P (2009). Conservation agriculture and smallholder farming in Africa: the heretics' view." Field crops research 114(1):23-34.

Govaerts B, Sayre KD, Goudeseune B, De Corte P, Lichter K, Dendooven L, Deckers J (2009). Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Till. Res. 103(2):222-230.

Govaerts B, Verhulst N, Castellanos-Navarrete A, Sayre K, Dixon J, Dendooven L (2009). Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Crit. Rev. Plant Sci. 28(3):97-122.

Håkansson I (1994). Soil tillage for crop production and for protection of soil and environmental quality: a Scandinavian viewpoint. Soil and Till. Res. 30(2-4):109-124.

Hobbs PR, Govaerts B (2010). How conservation agriculture can contribute to buffering climate change. Climate change and crop

production 1.
Howden SM, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H (2007). Adapting agriculture to climate change. Proc. Natl. Acad. Sci. 104(50):19691-19696.
Jat RA, Wani SP, Sahrawat KL (2012). Conservation agriculture in the semi-arid tropics: prospects and problems. Adv. Agron. 117:191-273.
Kagabo MD (2013). Participatory integrated watershed management in the north-western highlands of Rwanda, [Sl: sn].
Kagabo, Stroosnijder L, Visser S, Moore D (2013). Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. Soil Till. Res. 128:23-29.
Kassam A, Friedrich T, Derpsch R, Lahmar R, Mrabet R, Basch G, Serraj R (2012). Conservation agriculture in the dry Mediterranean climate. Field Crops Res. 132:7-17.
Kassam A, Friedrich T, Shaxson F, Pretty J (2009). "The spread of conservation agriculture: justification, sustainability and uptake." Int. J. Agric. Sustain. 7(4):292-320.
Kelly V, Mpyisi E, Shingiro, Nyarwaya JB (2001). Agricultural Intensification in Rwanda: An Elusive Goal. Food Security Research Project/Division of Agricultural Statistics Policy Brief. Ministry of Agriculture, Animal Resources and Forestry, Kigali.
Lanckriet S, Araya T, Cornelis W, Verfaillie E, Poesen J, Govaerts B, Bauer H, Deckers J, Haile M, Nyssen J (2012). Impact of conservation agriculture on catchment runoff and soil loss under changing climate conditions in May Zeg-zeg (Ethiopia). J. Hydrol. 475:336-349.
Li L, Huang, Zhang R, Bill B, Guangdi L, Kwong YC (2011). Benefits of Conservation Agriculture on Soil and Water Conservation and Its Progress in China. Agric. Sci. China 10(6):850-859.
Lobell DB, Burke MB, Tebaldi C, Mastrandrea MD, Falcon WP, Naylor RL (2008). Prioritizing climate change adaptation needs for food security in 2030. Science 319(5863):607-610.
Lubwama FB (1999). Socio-economic and gender issues affecting the adoption of conservation tillage practices. Kaumbutho, PG and Simalenga TE, (eds). pp. 155-160.
Lybbert TJ, Sumner DA (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. Food Policy 37(1):114-123.
Mashingaidze N, Madakadze C, Twomlow S, Nyamangara J, Hove L (2012). Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. Soil Till. Res. 124:102-110.
Mkoga Z, Tumbo S, Kihupi N, Semoka J (2010). Extrapolating effects of conservation tillage on yield, soil moisture and dry spell mitigation using simulation modelling. Phys. Chem. Earth. Parts A/B/C 35(13):686-698.
Morris NL, Miller PCH, Orson JH, Froud-Williams RJ (2010). The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment—A review. Soil Till. Res. 108(1-2):1-15.
Motzafi-Haller P (2005). Women in agriculture in the Middle East, Ashgate Publishing.
Mrabet R, Moussadek R, Fadlaoui A, Van Ranst E (2012). Conservation agriculture in dry areas of Morocco. Field Crops Res. 132:84-94.
Ndayisaba PC (2014). Effects of Inorganic and Organic Fertilizers on Nutrient Uptake, Soil Chemical Properties and Crop Performance in Maize Based Cropping Systems in Eastern Province of Rwanda.
Nduwumuremyi A (2014). Effects of different limes on soil properties and yield of irish potatoes (*Solanum tuberosum* L.) in Burera District, Rwanda.
NISR (2013). Seasonal agricultural survey report. Kigali, Rwanda: National Statistical office of Rwanda.
Rockström, Barron J, Fox P (2003). Water productivity in rain-fed agriculture: challenges and opportunities for smallholder farmers in drought-prone tropical agroecosystems. Water productivity in agriculture: Limits and opportunities for improvement 85199(669):8.
Rockström, Karlberg L, Wani SP, Barron J, Hatibu N, Oweis T, Bruggeman A, Farahani J, Qiang Z (2010). "Managing water in rainfed agriculture-The need for a paradigm shift." Agric. Water Manag. 97(4):543-550.
Rusinamhodzi L, Corbeels M, van Wijk MT, Rufino MC, Nyamangara J, Giller KE (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agron. Sustain. Dev. 31(4):657-673.
Rwanyiziri G, Rugema J (2013). Climate Change Effects on Food Security in Rwanda: Case Study of Wetland Rice Production in Bugesera District. Rwanda J. 1(1):35-51.
Safari B (2012). "Trend Analysis of the Mean Annual Temperature in Rwanda during the Last Fifty Two Years. J. Environ. Prot. 3(6):538-551.
Sanginga NS, Woomer PL (2009). Integrated soil fertility management in Africa: principles, practices, and developmental process, Free download form CIAT.
Sidhu HS (2014). Improving water productivity of wheat-based cropping systems in South Asia for sustained productivity. Adv. Agron. 127:157.
Singh B, Malhi SS (2006). Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil Till. Res. 85(1-2):143-153.
Six J, Ogle SM, Conant RT, Mosier AR, Paustian K (2004). "The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. Glob. Change Biol. 10(2):155-160.
Su Z, Zhang J, Wu W, Cai D, Lv J, Jiang G, Huang J, Gao J, Hartmann R, Gabriels D (2007). Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. Agric. Water Manag. 87(3):307-314.
Thierfelder C, Wall PC (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Till. Res. 105(2):217-227.
Thierfelder C, Wall PC (2010). Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. J. Crop Improv. 24(2):113-121.
Tscharntke T, Klein AM, Kruess A, Steffan-Dewenter I, Thies C (2005). Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecol. Lett. 8(8):857-874.
Turmel MS, Speratti A, Baudron F, Verhulst N, Govaerts B (2014). Crop residue management and soil health: A systems analysis. Agric. Syst. 134:6-16.
Valbuena D, Erenstein O, Homann Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC, Teufel N, van Rooyen A (2012). Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field crops Res. 132:175-184.
Varela AM (2001). Managing Agricultural Resources for Biodiversity Conservation. Case study Brazil, Cuba and Mexico. Study commissioned by ELCI, pp. 1-43.
Verdoodt A, Van Ranst E (2003). Land evaluation for agricultural production in the tropics. A large-scale land suitability classification for Rwanda.
Wallace JS (2000). Increasing agricultural water use efficiency to meet future food production. Agric. Ecosyst. Environ. 82(1-3):105-119.