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Towards Climate-Smart Agricultural Approach: Prospect for Smallholder Farmers in Semi-Arid Regions

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Abstract

Climate change has become a major threat to human developmental sectors in recent times. Agriculture is particularly vulnerable sector because it is highly dependent on climate variables. General decrease in total seasonal rainfall, accompanied by more frequent in-season dry spells are pervasive to sub-Saharan Africa, and significantly impact on crop and livestock production, and hence hamper food security in the region. The hardest hit by climate change is the rural smallholder farmers in the drier areas, owing to adaptive capacity and limited resources. As to carter the adaption needs of smallholder farmers to climate change, climate-smart agricultural approach provides much needed potential. However, to efficiently achieve climate-smart agriculture, evidence-base, and location specific framework that unpack complexity and define precise implementation pathway is urgently needed. This paper therefore, reviewed prospect of present and future climates change implications to smallholder farmers in developing countries. Thereafter, it drew upon a variety of current adaptation strategies within concept of climate smart agriculture, and assess the required support to increase the adaptive capacity of smallholder farmers' in semi-arid regions

Keywords: climate change, climate-smart agriculture, semi-arid regions, smallholder farmers

1. Introduction

Climate change has become a major threat to human developmental sectors in recent times. Agriculture is particularly vulnerable sector because it is highly dependent on climate variables. Change in climate variables directly affects agricultural production in one way to another. Predictions for semi-arid areas in Southern Africa suggest a general decrease in total seasonal rainfall, accompanied by more frequent in-season dry spells that will significantly impact crop and livestock production, and hence economic growth in the region(Twomlow et al., 2008). Crop failure due to drought is already common to Sub-Saharan Africa, and the hardest hit is the rural poor in the drier areas (Alliance for a Green Revolution in Africa (AGRA), 2014).

In recent cases, South Africa in 2015/2016 season experienced worst drought since 1982 and that mostly affected small-holder farmers because of being limited to resources. Both commercial and subsistence farming are subject to climatic effects, but compared to commercial agriculture, smallholder farmers are more exposed to climate change and usually do not have access to financial instruments such as credit and insurance to hedge against climatic risk, thereby leaving the poor and the marginalised exposed and more vulnerable to food insecurity. Different strategies are being investigated worldwide to assist crop producers to cope with rising global temperatures and carbon dioxide levels, along with reduced rainfall, soil moisture and water availability (Mbilinyi & Kazi, 2013; Otitoju, 2013; Sultana et al., 2009).

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Given that agriculture is the sector that can affect and affected by climate change in the area, it is important that farmers respond with the strategies that are aligned to the objectives of climate-smart agriculture. Climate-smart agricultural approach can contributes efficiently to food security, by addressing different aspects of current and projected climate change impacts through adaptation and mitigation actions. Mitigation attempts to minimize future climate change by reducing emissions through weakening the link between economic growth and carbon emissions (Hindering, 2011). In agricultural perspective, the fluxes of greenhouse gases can be reduced by managing more efficiently the flows of carbon and nitrogen in agricultural ecosystems (Smith et al., 2008). Adaptation on other hand, includes changes in management activities, institutional settings and infrastructure that enables effective response to the changes in climate that may occur (Klein, Holzkamper, Calanca, & Fuhrer, 2014). At the farm level, adaptation involves a combination of various individual responses and assumes that farmers have access to alternative practices and technologies available in the region.

Although climate-smart agriculture (CSA) objectives are well documented and supported at both global and local level (Lipper et al., 2014); adoption and implementation of climate-smart agriculture strategies vary among the regions based on combination of factors. In Sub-Saharan Africa, smallholder farmers, particularly those in semi-arid regions are likely to be more exposed and vulnerable to impact of climate change, and there is limited knowledge regarding the implementation and effectiveness of current measures in reducing exposure and vulnerability (Spear et al. 2015). As to carter the adaption needs of smallholder farmers, evidence-base, and location specific framework that will unpack complexity and define precise implementation pathway is urgently required. This paper therefore, reviewed prospect of present and future climates change implications to smallholder farmers in developing countries. Thereafter, it drew upon a variety of current adaptation strategies within concept of climate smart agriculture, and assess the required support to increases the adaptive capacity of smallholder farmers' in semi-arid regions.

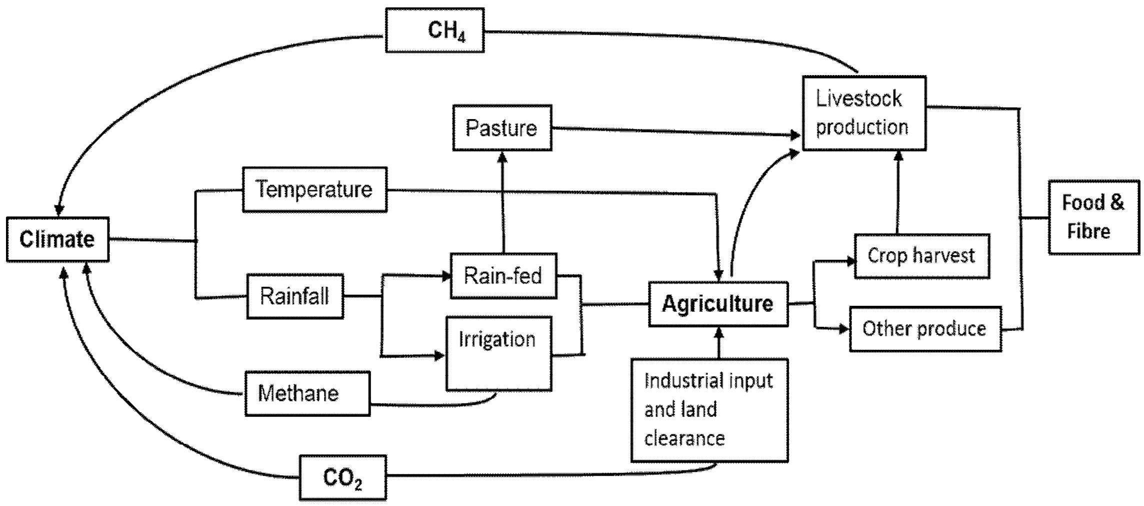
1. Implications Of Climate Change And Sustainable Agriculture

One of the key sectors that is already and will increasingly be affected by climate change is agriculture. This is particularly true for agriculture in developing countries, and especially for countries in sub-Saharan Africa (SSA) region. The region continues to experience rapid and uncertain changes in rainfall patterns and temperature regimes, which consequently threaten food production, increase the vulnerability of smallholder farmers, and results in food price shocks and increased rural poverty (Brown 2012; Alliance for a Green Revolution in Africa (AGRA) 2014). However, agriculture, even the low-input small-scale agriculture of Africa is both a victim and culprit relative to climate change. Climatic conditions influence agricultural food production, and in turn, that production produces feedback on the climate via increased emission of greenhouse gases (Figure 1). Agriculture, Forestry, and Other Land use contributed 24% of 2010 global greenhouse gas emissions, with the most emission coming from cultivation of crop and livestock, and deforestation (Tubiello et al., 2014). It was also emphasised that this estimate does not include the CO_2 that ecosystems remove from the atmosphere by sequestering carbon in biomass, dead organic matter and soils, which offset approximately 20% of emissions from this sector (Tubiello et al., 2014). Therefore, it is very fundamental to practice modern agriculture in a sustainable manner considering association that agriculture has with the environment.

As it can be noted from figure 1, changes in climatic variables have major implications for sustainable agricultural production, particularly for rain-fed crop production in semi-arid regions. The increase in temperature and reduced rainfall already have significant effects, as they lead to drought conditions, which potentially cause catastrophic yield reductions unless sufficient irrigation system is used, something which smallholder farmers are unable to do (Rurinda et al. 2014; Sarr, 2012). Furthermore, ongoing warning and drying reduces water which is available for irrigation; reduces soil fertility through increased oxidation of soil organic carbon; and it also increases incidence of pest, diseases and weeds (Issahaku & Maharjan, 2014). Consequently, proactive adaptation measures are urgently required, otherwise yields from rain-fed agriculture could be decreased by up to 50% by 2020 in semi-arid regions (Brown, 2012). The main factor of climate change is water stress, which significantly affect crop production in rain-fed farming systems under arid and semi-arid environments (Debaeke & Aboudrare, 2004). Although it does not occurs frequently, the impact of water stress can be turnaround, since too much seasonal rainfall cause flooding which lead to loss of production, and soil erosion.

For example, starting in December 2014, the Southern Region of Malawi received 400% higher rains than usual (compared to the Long Term Mean) causing the Shire River to reach its highest level in 30 years (OCHA, 2015). Recent studies indicated that smallholder farmers in Southern Africa are aware that climate is changing mainly through observations of rainfall and temperature trends over a long period of time; with reference to increase in temperatures and frequent drought both intra and between the seasons(Juana, Kahaka, & Okurut, 2013; Michigan State University, 2012; Murungweni, van Wijk, Smaling, & Giller, 2015).

Figure 1 Association between Agriculture and climate

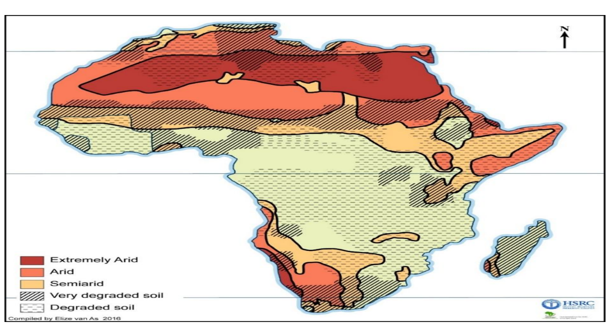


**In occasion of climate change, crop productivity will decline due to increase or decrease in temperature, as well due to change in rainfall pattern or amount. Livestock production is also affected due to lack of good quality grazing grass and lack of drinking water.*

2. Vulnerability Of Small-Holder Farmer's In Developing Countries

With a mean annual rainfall of approximately 450 mm, much of the central part of southern Africa is classified as semi-arid (Fig 2). In fact, semi-arid conditions in SSA regions are likely to increase with climate change, yet these regions are becoming more important to feed production zones due to increasing population pressure (Murungweni et al., 2015). Production systems in semi-arid regions of the world are often thought of as being particularly vulnerable to climate change. They are already climatically stressed with high temperatures, low rainfall and long dry seasons (Alliance for a Green Revolution in Africa (AGRA), 2014).Poor soil fertility due to increasing land degradation is also among common production constraints in sub-Saharan Africa. As the results, crop production in such regions is characterised by relatively small and variable yields among smallholder farmers (Cooper et al., 2008).

Fig 2: **Aridity and soil degradation zones in Africa**



In addition to above mentioned statements; harsh environmental conditions persist in semi-arid regions, smallholder crop growers in developing countries are further less productive because of interaction of climate change and variability with other non-climatic stressors. Their production failure therefore, can be seen as a function of the existing environmental and climatic conditions coupled with socio-economic constrains. As generally characterised by limited resources, smallholder farmers therefore depend on production systems that are sensitive to climate change such as dependence on rain-fed crop production (Ifad, 2011). Consequently, climatic and socio-economic factors in developing countries are largely contributors toward food insecurity and unstable livelihoods (Spear et al. 2015; Kori 2013). To this end, explicit climatic adaptation measures which best fit socio-economic status of smallholder farmers are urgently needed to achieve sustainable agriculture and food security. The next section will look at the concept of climate-smart agriculture (CSA), and how it can be achieved to promote food production at environmentally sustainable way.

4. Concept Of Climate-Smart Agricultural Approach

Given the current and future trend of climate change, escalating land degradation, and socio-economic burden; developing countries need to break ground into the practice of climate-smart agriculture (CSA) to achieve sustainable farming. As already defined, CSA can sustainably increase productivity, resilience (adaptation), reduce greenhouse gases (mitigation), and enhance achievement of regional food security and developmental goal. The approach focus on implementing proactive response strategies, rather than reactive strategies which have proven costly and ineffective for smallholder farmers. Lipper et al. (2014) asserted that "CSA promotes coordinated actions by farmers, researchers, private sector, civil society and policymakers towards climate-resilient pathways through four main action areas: i) building evidence; ii) increasing local institutional effectiveness; iii) fostering coherence between climate and agricultural policies; and iv) linking climate and agricultural financing''. As to enforce sustainability under current challenges, CSA identifies synergies and trade-offs among food security, adaptation and mitigation as a basis for informing and reorienting policy in response to climate change (Lipper et al. 2014).

4.1 Adaptation and Mitigation Approach

As to make agriculture more climate-smart, farmers seek the best combination of various farm-level management practices and varietal options. Interventions aimed at promoting conservation farming and adoption of hybrid seed varieties would be very instrumental in helping farmers improve yields despite the changing climate. As much as causing less damage to the environment, climate-smart agriculture also improved farmers' capital by, for instance, reducing their reliance on costly inputs (pesticides and chemical fertilisers).

4.1.1 Genotypic Adaptation

Development of climate-smart crop varieties through breeding is showing remarkable progress towards adaptation to climatic stress in semi-arid regions. Plant breeding has shown extraordinary significance in crop productivity even beyond prospect of climate change, from the view point of developing crops that adapt to particular environment; crops tolerant to diseases or pests; crops with improved yield and quality, and crops with shorter maturity or harvesting period (Acquaah 2007).

The most notable genotypic adaptations to water-limited environments is through: (i) drought escape, whereby the crop completes its life before the onset of terminal drought, (ii) drought avoidance, where the crop maximizes its water uptake and minimizes its water loss through evapotranspiration, and (iii) drought tolerance, where the crop continues to grow and function at reduced water contents (Ludlow, 1989; Gwata & Shimelis 2013). Remarkably, more than 34 new drought tolerant maize varieties have been developed over the past five years and deployed to over 2 million smallholder farmers in sub-Saharan Africa, empowering them to cope with climate change impacts on their livelihoods and food security (Cairns & Fisher, 2015). A study by Corobov (2002) in Moldova shows that the adoption of late-maturing maize hybrids as an adaptation measure engenders considerable yield enhancement.

The adoption of heat tolerant varieties of sorghum, millet, cotton, cowpeas and rice in Mali also attest to the yield- and welfare-enhancing effects of this adaptation measure (Butt et al. 2005). The degree of genotypic adaptation vary among crop species based on number of factors, including genetic diversity, trait heritability and genotype x environment (G*E) interaction.

4.1.2 Crop Substitution

Although breeding for tolerant crop varieties provide great opportunity to adapt to climate change, there are certain crops that lacks enough genetic diversity or either too costly to develop new varieties with adapted traits. In such case Issahaku & Maharjan (2014) alluded that, flexibility of farmers to adapt to changing socioeconomic and environmental conditions by changing crop type may therefore represent an alternative option to adapt to climate change. Up to date, the potential for adapting to climate change through crop substitution has received less attention (Rezaei et al. 2015), but there is high potential for smallholder farmer's to switch crop species of their choice, given predicted change in climate variables and limited resources. Some crop species are naturally adapted to semi-arid conditions, and subsequently likely to be less affected by climate change. Significantly, smallholder famers in Africa can be privileged to cultivate indigenous leafy vegetables, which require them no additional inputs and very adapted to semi-arid conditions, while being packed with essential micronutrients, such as iron and Vitamin A (Ebert, 2014).However, the strategy is more justified to the farmers, if the crops are substituted based on similar use, such as replacing maize with sorghum.

4.1.3 Conservation Agriculture (Soil, Water and Crop Management)

In event of the short rain season, planting early-maturing maize varieties which are planted in mid-November and mature around late February or early March provides potential adaptation to the farmer's in Southern Africa (Michigan State University, 2012). Yau and Ryan (2013) observed the negative correlation between common vetch and barley grain yields and temperature in May, which suggests that early sowing to induce earlier flowering and maturity to escape the hot summer may be an option to increase common vetch and barley grain yields. For smallholder farmers who only rely on rain-fed production systems, it is very advisable to improve crop moisture management to cope with warmer temperatures and prolonged intervals between rainfalls. Luers (2005) reported that farmers practicing improved soil fertility management were less vulnerable to increased temperatures than non-practicing farmers with respect to wheat production.

It is also important for farmer's to be proactive with regards to reducing soil erosion, runoff and flooding risk under this prevailing climate change. Landscape position is one of farm-level production strategy that has potential to adapt to both drought and floods. Low lying areas tend to have less risk of crop failure during a drought but can be vulnerable to flooding. Therefore, farmers in semi-arid regions can reduce risk of total crop failure by making a clever use of both the low lying and the upland areas depending on crops of their interest (Murungweni et al., 2015). The Zimbabwe-based Africa Conservation Tillage Network (ACT), recommends breaking the soil only where seeds are to be planted, as ploughing entire fields can degrade soil. Farmers are also advised to rotate crops to increase soil fertility and grow cover crops along with their main crop to prevent runoff (ACT-Network 2012; Cooper et al. 2013).

Although among smallholder farmers conservation agriculture is highly encouraged by socio-economic constrains, it also play integral role to mitigate climate change, while sustaining food production. Crop yields can be improved when farmers using approaches such as less tilling to conserve soil, integrated pest management, which favours ecological pest control over pesticide spraying, and improved management of soil nutrients (www.scidev.net. Accessed 11 Jul. 16). Some applicable farm-level management options associated with mitigation actions are presented in Table 1.

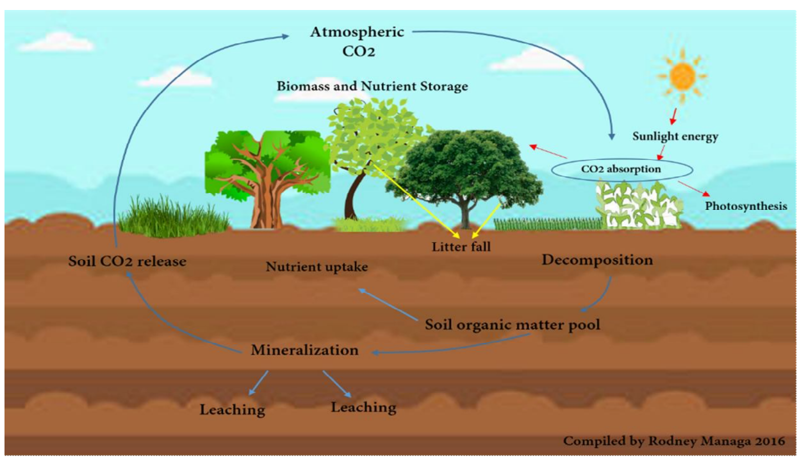
Table 1: **Greenhouse gas mitigation under conservation agriculture**

GHG mitigation actions	Farm-level management options
Carbon sequestration in soil	soil organic matter management and enrichment, reduced frequency of cultivation, soil conservation practices, improved grassland management
Carbon sequestration in perennial plants	increased area or use of perennial crops, farm forest management, agroforestry, natural regeneration, lengthened fallow periods, silvopastoral systems
Carbon emission reduction	Agricultural machinery emission management, avoided deforestation
Methane emission reduction	Improved livestock feed, peat soil management

Source: (CIAT 2012)

As pointed out on table 2, Carbon sequestration is a pivotal facet of climate change mitigation. Sequestration work by removing carbon from the atmosphere or preventing its release altogether by guarding it in a reservoir. As recognised by Kyoto Protocol(*international agreement linked to the United Nations Framework Convention on Climate Change*), net carbon emissions may be reduced either by decreasing the rate at which greenhouse gases are emitted to the atmosphere or by increasing the rate at which greenhouse gases are removed from the atmosphere through sinks, both of which can be achieved through sequestration (Ki-moon, 2008). Carbon dioxide (CO_2) is the most important GHG contributing towards climate change, and agriculture is one among major contributing sector, but it also provide mitigation potential. As laid out on figure 3, agricultural soils are among the planet's largest reservoirs of carbon and hold potential for expanded carbon sequestration, thus providing a prospect for mitigating the increasing atmospheric concentration of CO_2 (Friedrich 2010).

Figure 3: Carbon sequestration opportunity under conservation agriculture



** Practicing agro-forestry farming system promote carbon farming, and increase potential to reduces GHG emission or absorption captures and hold carbon in vegetation and soils.*

4.2 Prospect for food security under concept of climate-smart agriculture

As much as agriculture is projected to be a major source of emissions growth, this also threatens future food security (Dercon, 2007). Climate-smart agriculture (CSA), therefore prioritizes food security but also considers the potential and costs of capturing mitigation benefits. Mitigation under the concept of CSA is leveraged to support food security and adaptation, rather than hampering them. Given how widespread changes in rainfall and temperature patterns threaten agricultural production, CSA is the only approach for transforming and reorienting rain-fed agricultural system to support food security under the new realities of climate change (Lipper et al., 2014).

In regards to sub-Saharan Africa, about 70% of agricultural output derived from rain-fed small-scale farms (Alliance for a Green Revolution in Africa (AGRA), 2014), hence moving towards climate-smart agricultural approach become priority to achieve food security in the region. As already highlighted somewhere in this paper, achieving food security has now become great challenge due to climate change, and requires increasing adaptive capacity of farmers as well as increasing resilience and resource use efficiency in agricultural production systems.

5. Required Support To Efficiently Adapt To Climate Change At Farm Level

The implications of climate-smart agriculture are very positive towards sustainable agricultural production, and hence promote food security in the developing countries. However, there are pillars which are essential to coordinate the development and implementation of adaptation strategies. This paper argues that it takes nothing either than agricultural technical, economic/financial and institutional support to achieve the objectives of climate-smart agriculture at both global and local level.

5.1 Agricultural technical support

The adaptability of smallholder farmers to cope with changing climate in semi-arid zones is possible, but it require that certain barriers or limitations be overcome. There are a number of barriers to sustainability of adaptation strategies that have been reported in the literature, these includes but are not limited to unspecific prediction. For correct measures to be applied predictions need not to happen for the sake; but these need to focus at the environment of concern? According to Masinde & Bagula (2011); providing smallholders farmers with customized forecast information that can reliably inform them about the onset, cessation and intra-seasonal variations in order to reach decisions such as what, when and how to plant/harvest will be a step in the right direction. As alluded by Phiiri et al. (2016), investing in early warning systems is pivotal to facilitate adaptation to climate change among smallholder farmers. The early predictions at local level, particularly those focused on extreme events such as drought would benefit smallholder farmers, as they can make timely farm-level decisions. As already reported earlier in this paper, marginalized smallholder farmers in dry areas are likely to be most seriously hit by the shifts in moisture and temperature regimes as a result of the global climate change. To help them cope with the challenges, IRRI (2010) emphasised the need for a new paradigm in agricultural research and technology transfer that makes full use of modern science and technology in conjunction with traditional knowledge.

In line with aforementioned, a participatory analysis by Rurinda et al. (2014) shows that there is little knowledge available to understand the relationship between smallholder farmers of different endowments and vulnerability to climate variability and change relative to other stresses such as soil fertility depletion. Therefore related vulnerability analyses are needed to best fit adaptation options particularly in diverse environments with limited resources (Luers 2005). Research on vulnerability frameworks are increasing, but are more on understanding the theoretical concept and lack practical relevance for intervention (Janssen 2007). It has been observed that impacts of climate variability and change are context and location specific. As such, local vulnerability analyses are required to derive lessons on the how the relationship between smallholder farmer resources endowment and vulnerability to climate variability and change is mediated by the socio-economic and environmental resources present in the system (Rurinda et al., 2014). In many cases, the vulnerability analysis tend to be done based on impact of single climate variable (Eriksen et al., 2011; Luers 2005). As the results, it become difficult to devise effective adaption strategy to particular area, since other climatic factors may be concealed (O'Brien et al., 2006). Thus, as supported by Rurinda et al. (2014), analysis of vulnerability requires a holistic systems approach recognising multiple climatic exposure as well as social and biophysical constraints.

5.2 Economic/financial support

In current socio-economic situation, most of smallholder farmers in developing countries are restricted by high cost of production inputs. Every new technique or practices comes at the additional cost to the famers, consequently limit their capacity to hedge against climatic risks. According to USAID focus group interviews, farmers in sub-Saharan Africa complained of lack of income to purchase hybrid seed.

The relatively well-off farmers are able to buy their own seed that is suitable for the area, but the poor farmers who cannot afford to buy their own seed are left without a choice but to plant the wrong varieties. Although the governments tend to offer financial support to smallholder farmers through different training programmes and through research funds, new funding model is required to complement the support towards climate change adaptation. It does not make any contribution for government to invest on technology development, whereas the targeted farmers will not afford it. Particularly to Southern Africa, most required economic support to address climate change in agricultural sector are not limited to financing change in farming practices (Table 2)

Table 2: Economic support required to adapt to climate change at agricultural sector

Adaptation actions	Economic/financial support
Changes in farming practices	Spatial planning of rural agricultural development/land reform Subsidised drought-resistant seeds Funding of extension services Improved financial services (credit and insurance) Support of joint ventures to farm on spatially separated areas Increased support to land reform projects Support of agricultural cooperatives
Improved natural resource conservation measures	Funding of buyout schemes and abattoirs to reduce stocking rates during drought
Research and monitoring of climate, ecosystem, and socio-economic parameters	National academic research funding support to climate change projects (e.g. research on viability of new cultivars) Funding of national monitoring programmes

Source: (Turpie and Visser 2015)

5.3 Institutional support

As illustrated elsewhere in this paper; part of dealing with climate change is through adaptation. Adaptation is knowledge intensive and often the capacity constraints are largest in this area. As the realities of climate change continue to unfold; it is important to recognize that governments need to prioritize building skills and capacities both as a short term and as a long-term project (Pettengell, 2015).A study by Juana et al. (2013)shows that education and awareness about climate change impacts and therefore coping capacities is very low among most farmers partly due to weak institutional coordination and support. In order to improve the efficacy of institutions responsible for raising public awareness and educating all sectors of the society about climate change; sufficient resources need to be made available. In addition; vulnerable populations that are predominant smallholder farmers (i.e. women and elderly) have specific adaptation needs and thus policies must recognize different issues affecting different groups and should be tailored to the specific needs. Adaptation at all levels must be read and understood within the boundaries of local context (Pettengell, 2015).

Enforcement on agricultural extension institutions is also fundamental to support farmers' with less education and scientific knowledge, to efficiently apply recommended adaptation strategies. Some developing countries tend to have government extension service to support particularly smallholder farmers, but typically fail to make impact due to number of factors. Some of areas that need intense improvement to complement government extension services are as follow:

i) Proper training – training and new approach offered to smallholder farmers should be relevant and intend to solve the real challenges
ii) Competitiveness of extension agents – government agriculturist should be able to understand production system of target farmers, and able to exploit broad base research finding, put it into local context which best fit adaptation requirements in specific climatic location

iii) Participatory approach – farmers need to be involved in all activities intended to find solution for their farming problems, in this way, research objectives must be driven from farmers themselves, and most of research practices should be tested on farmer' sites

iv) Availability – extension services should be always available to smallholder farmers when they need it, there must be enough number of agriculturists focus at particular regions, and always visit the farmers for observations and advise

6. Conclusions

This paper reviewed that in general, smallholder farmers in developing countries are less effective to adjust their farming strategies in response to climate change, owing to limited resources and knowledge capacity. Given the current and future trend of climate change, escalating land degradation, and socio-economic burden; countries in sub-Sahara Africa need to break ground into the practice of climate-smart agriculture (CSA) to achieve sustainable farming, as well as to contribute towards mitigating global climate change. Strategies, ideas and opinions that identifies synergies and trade-offs among food security, adaptation and mitigation as a basis for informing and reorienting policy in response to climate change are highly recommended.

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