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Implications of Climate Variability and Change for Smallholder Crop Production in Different Areas of Zimbabwe

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Abstract: Sustainable food production in the rain-fed smallholder sector of Zimbabwe is imperative in current and future climates given the increasing proportion and role of the sector in food security. Backgrounds of the smallholder sector include low resource bases, declining soil productivity, climate variability and increasing human population. Impacts of climatic and non-climatic variables on crop production vary in different Agro-Ecological Regions (AERs). The study identifies the main climatic opportunities and constraints for sustainable rain-fed smallholder crop production systems in current and future climates. Estimated changes in rainfall and temperature by 2050 are not likely to negatively impact crop production in smallholder areas in AER I, increases in temperature may have negative impacts for most of AER III and IV. Most of AER V is likely to become unsuitable for sustainable maize production. Overall projections indicate increased differences in agricultural potential between smallholder farmers in AER I compared to those in AER II and III as well as those in AER IV and V and different management options. Proposed adaptation and coping strategies in AER I and some in AER II include intensification of agriculture and optimization of both C3 and C4 crop production while in AER III to V adoption of stress tolerant crops for family subsistence may be imperative.

Keywords: Adaptation, climate, smallholder, sustainable production, temperature

INTRODUCTION

Agricultural production in sub-Saharan Africa (SSA) is expected to be mainly negatively impacted by 2050s climates. Average surface temperature is likely to rise by between 3-7°C and drier conditions are mainly predicted for southern Africa for the 2050s (Hulme *et al*., 2001; Christensen *et al*., 2007). Decreases in early summer rainfall as well as increases in late summer rainfall in the eastern parts of southern Africa (Tadross *et al*., 2005) and higher risks of drought are also projected (Boko *et al*., 2007). Warmer 2050s climates are mainly expected to impact production negatively in most of Sub-Saharan Africa. Mean decreases of about 12% in production of rain-fed cereals such as wheat, maize and rice in Africa by 2080 due to climate change are estimated (Christensen *et al*., 2007). In Zimbabwe maize productivity in some agricultural production zones may decrease primarily as a result of temperature increases (Makadho, 1996; Jones and Thornton, 2003). Projected changes in temperature and rainfall for the 2050s may present varying opportunities and constraints to current ones for different rain-fed smallholder farmers. Assessment of barriers, climate constraints, adaptation options and limits for current and 2050s climates in particular for the smallholder farmer contributes for progressive adaptation, long term technological strategies for climate change and appropriate climate policy. This study gives an overview of current climates, constraints and opportunities, expected 2050s temperature and rainfall, 2050s climatic constraints and opportunities for smallholder farmers in different AERs. Options for sustainable crop production for the different regions were also suggested with a view to strengthening climate research, planning and policy.

AGRICULTURAL PRODUCTION AND THE SMALLHOLDERS IN ZIMBABWE

Agricultural sectors in Zimbabwe include the smallholder sector; small to medium scale commercial, large scale commercial and corporate estates. The smallholder sector which expanded due to the land reform program (Chimhowu *et al*., 2009) consists of communal areas, the old resettlement areas and the

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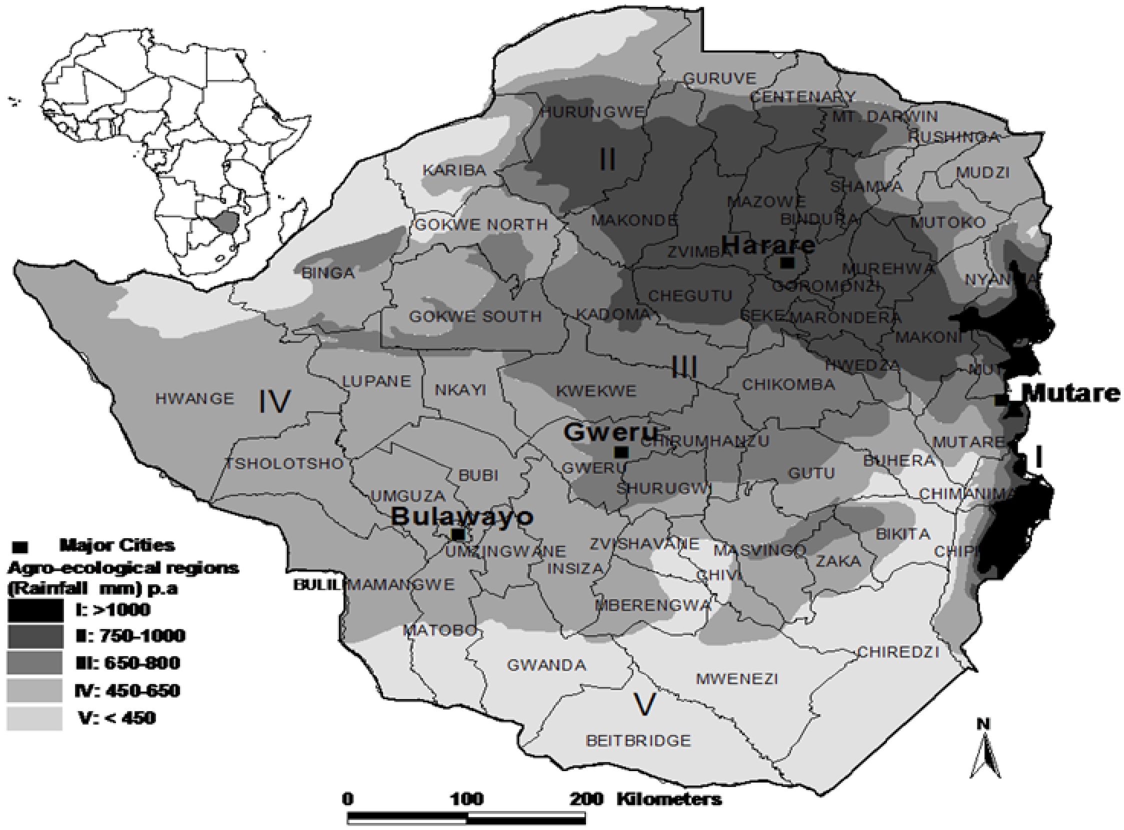

Provinces key

Provinces	Districts
Manicaland	Buhera, Chimanimani, Chipinge, Makoni, Mutare, Mutasa, Nyanga
Mashonaland Central	Bindura, Guruve, Mazowe, Mbire, Mukumbura, Muzarabani, Rushinga, Shamva
Mashonaland East	Chikomba, Goromonzi, Hwedza, Marondera, Mudzi, Murehwa, Mutoko, Seke, Uzumba-Maramba-Pfungwe
Mashonaland West	Chegutu, Hurungwe, Kadoma, Kariba, Makonde, Zvimba
Masvingo	Bikita, Chiredzi, Chivi, Gutu, Masvingo, Mwenezi, Zaka
Matabeleland North	Binga, Bubi, Hwange, Lupane, Nkayi, Tsholotsho, Umguza
Matabeleland South	Beitbridge, Bulilimamangwe, Gwanda, Insiza, Matobo, Umzingwane
Midlands	Chirumhanzu, Gokwe North, Gokwe South, Gweru, Kwekwe, Mberengwa, Shurugwi, Zvishavane

Fig. 1: Agro-ecological regions, provinces and districts of Zimbabwe; ICRISAT, GIS services

small-holder schemes newly acquired from large scale commercial farms known as A1 farms. Figure 1 show distribution of AERs and associated districts in Zimbabwe where smallholder farmers are located. As of 2000, communal land was 41.14% and old resettlement areas were 9.3% of total agricultural land in the country. Of the land 74% was in AER IV and V, 17% in AER II and III and only 9 in AER I. As of 2005 smallholder farms, including the newly resettled A1 farms, constituted 75.60% of total agricultural land in Zimbabwe (Ministry of Agriculture, 2007). Agricultural potential and crop production of the smallholder sector decreases from Agro-Ecological Region (AER) I to AER V mainly due to differences in mean annual rainfall and reliability, soil differences (Vincent and Thomas, 1960) in addition to management practices which are influenced in part by smallholder socio-economic environments.

Smallholders produce the largest proportion of maize grain compared to other agricultural sectors (Ministry of Agriculture, 2007; Ministry of Agriculture and Mechanization and Irrigation Development, 2012). Communal areas' contribution to maize production was 40 and 43% in the 2011/2012 and in 2010/2011 seasons respectively, the A1 sector contributed 23 and 24% in the 2011/2012 and in the 2010/2011 season respectively and the old resettlement areas contributed 11 and 5% in the 2011/2012 and in 2010/2011 seasons, respectively (Ministry of Agriculture and Mechanization and Irrigation Development, 2012). The highest proportion of the smallholder population is in AER IV and AER V (Chimhowu *et al*., 2009; Mehretu and Mutambirwa, 2006) which has the least agricultural potential (Vincent and Thomas, 1960) and is more vulnerable to the impacts of climate change. Some local maize varieties have yield potentials of more than 5 ton/ha.

Mean maize yields fluctuate around one ton per ha in high potential areas such as in AER II and III while in AER V grain yields are mostly below 500 kg/ha (FAO/WFP, 2010). The proportion of maize total area in the smallholder sector decreases from AER I to AER IV, while the proportion of area allocated to sorghum and other small grains such as pearl millet is highest in the drier AERs (FAO/WFP, 2010).

Biophysical and socio-economic background of smallholder farmers: Small land holdings that are generally between 2 to 3 hectares household, declining soil productivity (Nyamangara *et al*., 2000; Mafongoya *et al*., 2007); land degradation (Elwell and Stocking, 1976; Whitlow, 1988; Hamandawana *et al*., 2005); low soil organic matter content and low and declining fertilizer use (Bhondayi, 2004; Funk and Brown, 2009). Most smallholder farms are located in areas with sandy and generally infertile soils that are deficient in N, P and S and with low cation exchange capacity (Grant, 1967a, b; Nyamapfene, 1991). Agro-ecological region I mainly have fertile red soils while AER II, III and IV soils are mainly grayish brown sands and sandy loams derived from granitic rocks that are associated with acidity, low cation exchange capacity and poor water holding capacity. AER V soils are variable and include vertisols, brown loam soils and sands and sandy loams (FAO and ACFD, 1999). Many smallholder households have labor constraints (Mudimu, 2003) particularly during peak periods for production, inadequate access to draft power (Gambiza and Nyama, 2000; Mudimu, 2003; Ncube *et al*., 2009) and limited resources (e.g., capital, agricultural equipment). Average labor units in smallholder households are about 2.5 adult equivalents, household require at least 3 adult equivalent units for 3 ha of crop and 5 for critical labor periods (Mudimu, 2003).

Climatic constraints in current and future climates for different AERs: In addition to soil and socio-economic characteristics, rainfall and temperature largely account for regional variations in rain-fed African agriculture (Kurukulasuriya and Mendelsohn, 2008; Nhemachena *et al*., 2010). In Zimbabwe differences in farming characteristics and yields have mainly been attributed to rainfall differences. For example average maize yields in smallholder areas for high potential areas/districts ranged from 4.9 to 6.9 ton/ha and from 1.1 to 3.7 ton/ha for low potential areas during the 2003 season (Pass, 2003). The national mean annual rainfall is 655 mm while the mean is 300 mm in the low-lying Limpopo Valley (AER V; Fig. 1) to the south of the country and more than 1000 mm per annum in some AER I regions. Length of growing season ranges from 170-200 days for AER I to 70-100/130 days for most of AER IV. Parts of Zimbabwe have been characterized by significant inter-annual and decadal variability of the onset of the rains from 1979-2001 (Tadross *et al*., 2007). Mean annual temperatures are low relative to the geographic location as a result of the relatively high altitude. Mean annual temperature varies from less than 15-18°C and can rise up to 30°C in the AER I around October and in AER V ranges from 23-25°C but can rise to over 40°C in summer (Chagutah, 2010; Gambiza and Nyama, 2000). In Zimbabwe productivity, particularly of maize, is lowest in low lying areas where rainfall is low and temperature is high. For example in Chiredzi (AER V) where mean annual rainfall is generally below 500 mm and mean annual temperatures range from 20-30°C (Unganai and Murwira, 2010; FAO/WFP, 2010) average maize yields are generally about 500 kg/ha.

Implications are that warmer climates will impact crop productivity differently under smallholder conditions. Nhemachena *et al*. (2010) showed that the net revenues for specialized crops/livestock and mixed crop-livestock farming systems rise with increasing temperature up to 24°C. Asseng *et al*. (2009) noted that 2-3°C increases in temperature may increase agricultural production in high rainfall areas and 1-2°C increases in some semi-arid regions may be detrimental to production. Annual temperatures are projected to increase by about 3°C for the 2050s, with respect to 1961-90 baselines, using various global circulation models (Hulme *et al*., 2001; Christensen *et al*., 2007). Fairly large uncertainty exists with various emissions scenarios especially in terms of precipitation. Four of the GCMs used by Hulme *et al*. (2001) suggest wetting while three suggest drying and estimated changes in rainfall of ±5 to 15%. Christensen *et al*. (2007) projected mean precipitation decreases of about 10% in Zimbabwe under the A1B emissions scenario. Projections are that warmer climates will have the most significant negative agricultural production impact in semi-arid sub-Saharan Africa (Makadho, 1996; Mendelsohn *et al*., 2000; Jones and Thornton, 2003; Christensen *et al*., 2007; Thornton *et al*., 2011). Maize productivity in Zimbabwe is estimated to decrease under non-irrigated and irrigated conditions in some agricultural production zones of Zimbabwe primarily as a result of temperature increases (Makadho, 1996). Variable effects of increased temperature on short season maize variety yields were shown using the CERES -Maize model in different AERs (Makadho, 1996). Masvingo (AER IV) was projected to be impacted the most with yields as low as 40 kg/ha compared to Karoi (AER II) and Gweru (AER III) with yields of about 2.5 ton/ha. Burke *et al*. (2009) estimated that there may be more extremes in temperature not experienced in sorghum and pearl millet regions in sub-Saharan Africa for 2050s while precipitation changes may be considerably smaller. Precipitation effects include rainfall distribution variability and shortening of the length of growing season (Nyabako and Manzungu, 2012; Burke *et al*., 2009) but large uncertainties exist with respect to precipitation changes. Fischer *et al*. (2005) projected some southern areas of the country will not be suitable for cereal production.

In AER I average annual temperatures are 10-15°C in parts of Nyanga district, 15-20°C in Chimanimani and Chipinge areas (Nyabako and Manzungu, 2012) and mean annual rainfall, mainly above 1000 mm (Vincent and Thomas, 1960). Rainfall and temperature are not normally major limiting factors to production during the growing season. Growing seasons characteristically range from 170-200 days. For the 2050s mean annual temperatures ranges of 15-20°C and mean annual rainfall mainly above 1000 mm were projected, using the CGCM 3.1-T47 model produced by Canadian Centre for Climate Modeling and Analysis (CCCMA; Nyabako and Manzungu, 2012). Crop production in this AER may benefit from increased CO_2 concentration. Climatic factors are not likely to be major constraints in crop production.

In AER I and II climate variability and mid-season droughts are some of the climatic constraints to crop production for smallholder farmers. Rainfall totals and temperature in normal seasons are not usually major limitations to crop production. Most AER II districts including Mazowe, Bindura, Zvimba, Makonde and Goromonzi districts receive between 800-1000 mm while most districts in AER III which include Kadoma, Chikomba, Kwekwe districts receive 650-1000 mm (Nyabako and Manzungu, 2012; Vincent and Thomas, 1960). Average annual temperature for most AER II districts and some in AER III such as Kwekwe, Chikomba, Chirumhanzu, Hwedza are 15-20 and 20-25°C for other areas such as Kadoma and Gokwe south districts, Zaka and Masvingo (Vincent and Thomas, 1960; Nyabako and Manzungu, 2012). Mean annual rainfall of 650-1000 mm in most of AER II and III including Makonde, Hurungwe and Zvimba districts in AER II and Kadoma, Gokwe South, Gweru and parts of Chirumhanzu in AER III districts is projected for 2050s as well as mean annual temperature between 20-25°C. These means are currently experienced in AER IV and V areas such as Chiredzi, Lupane, Tsholotsho and Hwange where crop production is low.

Low erratic rainfall contributes to low yields in AER IV. Most AER IV districts receive 450-650 mm annually (Vincent and Thomas, 1960) while the mean temperatures lie between 15-20 and 20-25°C for some districts e.g., Lupane, Tsholotsho and Hwange districts (Nyabako and Manzungu, 2012). Mean annual temperature is projected to be between 20-25°C for most of these districts in the 2050s while rainfall will mostly be below 450 mm annually. Hence high temperature may have added effects of reducing yields in future climates.

In AER V districts, such as Chiredzi, low and erratic rainfall patterns, high mean annual temperature and temperature extremes mainly account for poor germination, low yields and crop failures in poor seasons (Unganai and Murwira, 2010). Low mean annual precipitation combined with extreme temperatures, effect high evapo-transpiration and reduced yields (Porter and Semenov, 2005; Dixon, 2009). Most AER V districts to the west of the country which include Kariba, Binga and Hurungwe receive 450-650 mm annually while some AER V districts in the south of the country i.e., Beitbridge, Gwanda, Matobo and Bulilimamangwe receive less than 450 mm annual rainfall (Vincent and Thomas, 1960). AER V districts to the south of Zimbabwe have mean of 20-25°C and those to the north -west i.e. Kariba and Binga in AER V have means of 25-30°C (Nyabako and Manzungu, 2012). Mean annual rainfall and temperatures are higher for AER districts to the north compared to those in the south. Mean annual temperatures of 25-30°C for parts of Chiredzi and Beit-bridge districts are projected in 2050s climates and 25-30°C to the north for Kariba, Binga, Gokwe-north and most portions of Hurungwe, Guruve and Centenary districts. High temperature extremes are likely to increase crop moisture stress thus most AER V may become completely unsuitable for crop/maize production (Makadho, 1996; Nyabako and Manzungu, 2012; Tadross *et al*., 2007).

Managing temperature and precipitation constraints in smallholder production: Rainfall amount and distribution is one of the main climatic limiting factors to production in addition to biophysical and socio-economic challenges. A high proportion of the smallholder area will continue to be rain-fed part due to the high costs associated with irrigation investment. The added effects on increased temperature will pose new challenges to most smallholder areas particularly in the drier AERs of the country. Temperature is projected to negatively impact production in particular of maize crop, particularly in AER IV and V districts south of the country (Makadho, 1996; Burke *et al*., 2009). Adaptation and coping to climate change and variability is a progressive process. Adaption and coping to changes in rainfall and temperature by different smallholder farmers requires climate change planning and policies which are agro-ecological region and area specific. Strategies which farmers use in dealing with climate variability include crop choices; soil and water management strategies, timing of operations among others. New challenges posed by 2050s climates may require new innovations and technologies or strategies adapted from other regions with anticipated 2050s climate characteristics for improved livelihoods.

Coping and adaptation options for smallholder farmers in low rainfall areas include among others crop choices (Kurukulasuriya and Mendelsohn, 2008), use of in-situ rain water harvesting strategies (Nyagumbo, 1999; Twomlow and Bruneau, 2000; Rockström, 2003; Mutekwa *et al*., 2009) and shifting of planting dates. Smallholder farming systems rely on crop choices for adaptation to different climates in particular temperature differences (Kurukulasuriya and Mendelson, 2008). In crop choices temperature elasticity is generally larger than precipitation elasticity across several African countries (Kurukulasuriya and Mendelsohn, 2008). Maize is grown throughout the selected African countries. Maize is better suited to the higher rainfall Savannah rainforest zones (Lobell *et al*., 2008). In cooler regions of Africa maize-beans and sorghum are the main farmers' crop choices and in hot regions cowpea and millet (Kurukulasuriya and Mendelson, 2008). In dry African regions farmers prefer millet and sorghum and in wet regions maize-beans, cowpea-sorghum or maize-groundnut combinations (Kurukulasuriya and Mendelson, 2008). Crop combinations which included maize-beans, cowpea-sorghum and millet-groundnut were noted for harsh conditions. Using APSIM-Sorghum (Turner and Rao, 2013) showed that sorghum yields of small-holder farmers will not be immediately reduced by warmer temperatures but can be increased using fertilizer in some drier eastern and southern Africa. Lobell *et al*. (2008) noted that among tropical cereals the shorter-season pearl millet is better adapted to heat and drought stress of the sub-Sahara Sahelregion than sorghum, which is more widely cultivated in the wetter Savannah zone. Crop choices will therefore be important adaptation options for smallholder farmers in warmer climates. In AER IV and V crop choices may be one of the significant adaptation options in future climates. Shifts in seasons anticipated in most AER II to V imply that use of short season varieties in addition to crop choices will be an important strategy for managing climate change and variability. Switching of crop choices as adaptation options for crop production in different African climates are also influenced by a combination of factors which include soil characteristics and precipitation (Kurukulasuriya and Mendelson, 2008; Mutekwa, 2009) as well as market costs of seed and prices of grain harvests.

Use of rainwater harvesting and management (RWHM) technologies by smallholder farmers, can improve productivity (Biazin *et al*., 2012). Effectiveness will in part depend on soil types as well as patterns of rain. Water management techniques include planting basin and ripper tillage systems, dead level contours and infiltration pits. Average maize yield of about 2.8 tons per ha in land under *fanya juus* treatment were obtained in AERs IV and V in Zimbabwe (Motsi *et al*., 2003). Maize yields of about 3 ton/ha were obtained by smallholder farmers under tied-ridges compared to averages of about 1.5 ton/ha under conventional tillage treatments (Motsi *et al*., 2004). Tied furrows increased sorghum yields 4-79% in clay soils, 29-100% in medium textured soils and no or potentially negative effects in sandy soils in AER V (Whiteside *et al*., 1998). Other strategies to maximize

Table 1: Implications of 2050s climates for rain-fed smallholder farmers in different AERs of Zimbabwe

AER	Opportunities and constraints to agriculture in 2050s climates	Options for adaptation in smallholder areas
I	**Opportunities:** CO_2 enriched environment combined with high precipitation and cooler temperature. **Constraints:** C3 weeds may increase competition for C4 food crops such as maize, sorghum, millets Climate variability	• Soil fertility management options-wider options • Breeding crops for disease tolerance and high yields • Use of long season, medium and short season varieties • Weed management • Horticulture, legume production • Intensification of crop production
II	**Opportunities:** CO_2 enriched environment. **Constraints:** Variations in rainfall distribution, Potential threat from weeds due to enhanced CO_2 concentrations; Shorter growing season; Soil constraints due to current sub-optimal management practices and socio-economic constraints Climate variability	• Soil fertility management options-inorganic fertilizers, organic matter, integrated soil fertility management • Soil moisture management options-rain water harvesting • Early planting • Short season maize varieties • Multiple strategies for soil moisture management • intensification of crop production
III	**Opportunities:** CO_2 enriched environment. **Constraints:** • Seasonal climate (rainfall) variability • Low precipitation • Increased mean annual temperatures and temperature extremes • Reduced soil fertility due to declining soil fertility from current farm management practices	• Stress tolerant crops/variety e.g., sorghum • Short season varieties • Soil fertility management options • Diversification from crops to livestock • Multiple strategies for soil moisture management • Increase arable land per household
IV	**Opportunities:** CO_2 enriched environment. **Constraints:** • High temperature • Low precipitation • Seasonal climate variability • Poor soil fertility in most areas	• Stress tolerant crops/variety • Short season varieties • Soil fertility management options • Shifts from crops to livestock extensive farming • Multiple strategies for soil moisture management • Increase arable land per household • Diversification of livelihoods
V	**Opportunities:** CO_2 enriched environment. **Constraints:** • High temperature • Low precipitation • Seasonal climate variability-high occurrence of mid-season droughts • Poor soil fertility in most areas	• Stress tolerant crops/variety (e.g., Pearl millet) • Soil fertility management options limited • Shifts from crops to livestock extensive farming • Multiple strategies for soil moisture management • Increase arable land per household • Diversification of livelihoods • Irrigation

water usage include early planting/dry planting and shifting planting dates in response to climate indicators and weather forecasts (Phillips *et al*., 2002). In semi-arid rain-fed cropping systems, productive water use is quite low partly due to poor soil fertility and management practices necessitating enhanced soil management under climate change. Soil fertility management technologies for smallholder farmers under climate change include use of inorganic fertilizers, organic fertilizers such as legumes, animal manures, integrated nutrient management strategies as well as agro-forestry. Choice of methods will depend on resource availability, affordability, applicability in the different climates and biophysical environments.

Uptake of technologies for soil and water management is relatively low in smallholder sector. Barriers in the smallholder sectors include lack of appropriate technologies and appropriate equipment, labor constraints, lack of knowledge; resource limitations (Nhemachena *et al*., 2010), capital for investment as well as traction constraints. Mazvimavi and Twomlow (2009) showed institutional support and agro-ecological location to strongly influence adoption intensity of different conservation farming components. There is need for intensifying platforms for relevant research and technologies through innovation platforms which involve different stakeholders. Shifts in macro-economic and socio-economic conditions may influence rate of uptake and adoption of these technologies. Appropriate technologies which are gender sensitive may also enhance adoption and effectiveness.

Projected increase in atmospheric CO_2 concentrations may also present opportunities and constraints for crop production by smallholder farmers in Zimbabwe. Benefits accrued from enhanced photosynthesis are expected to be greater for C3 plants compared to C4 plants (Dixon, 2009; Yang *et al*., 2006; Tubiello *et al*., 2007) and annuals compared to perennial plants. C3 plants in smallholder sectors include groundnut, bambara-nut, cowpea in drier AERs and in addition sugar-bean and soya-bean for the wetter areas. Potential effects of increased CO_2 concentrations will also depend on water and nutrient availability and the extent to which temperature increases. Table 1 summarizes the main constraints and opportunities due to shifts in climates as well as options which may be available for sustainable crop production in 2050s climates. However smallholder agriculture is heterogeneous and there are also livestock interactions that may overall reduce the impacts of climate on smallholder crop production.

CONCLUSION

This study outlined the opportunities and constraints which may be presented by 2050s climates. Many AERs IV and V smallholder areas may become unsuitable for production, especially for maize under rain-fed conditions. Climate in 2050s may contribute to increased productivity in some areas e.g., AER I. Fairly large uncertainty exists with various emissions scenarios especially in terms of precipitation, including onset of the rainy season and season length, thus uncertainties of impacts. Smallholder farmers will therefore face different degrees of difficulties in adapting in diverse socio-economic environments thus the need for wider options and investment in climate adaptation and reducing socio-economic constraints.

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