Policy Brief

Impacts of climate change on agriculture: *What, when, where and how?*

Key Messages

- A systematic increase in the maximum and minimum temperature is evident since late nineties. Average annual minimum temperatures Dodoma station increased at the rate of 0.0130C and maximum temperature has increased by 0.0360C every year from 1980-2010. Minimum and maximum temperature for Morogoro station has increased respectively 0.0360C and 0.0440C every year.
- Though all GCMs predicted a general increase in maximum and minimum temperatures at all locations, there are differences in the magnitude of this increase The median values for the 20 GCMs show the decline of rainfall in mid centaury period on both RCP4.5 and RCP8.5 by -1.1% and -0.8%, respectively. Increase in rainfall towards end century-periods are 1.4 and 5.0% under RCP 4.5 and RCP 8.5, respectively.
- Climate change has both positive and negative impacts on maize yields. Simulation results with APSIM indicate that maize yields will increase by 5% towards mid-century under RCP 4.5 emission scenario in LHZ1. The increase in yield is also observed in LHZ 2 for both mid and end century (under RCP 4.5). Under RCP 8.5 scenario, yield declined 20 – 30% towards end of century. DSSAT indicate there will be no substantial maize yield increase in both LHZ1 and LHZ2.
- Model results indicate potential gains in maize yield in all livelihoods under adapted future climates by all GCMs on APSIM. Highest gains are observed in LHZ2 where adopted condition indicates more than 100% yield increase. APSIM simulations show that this adaptation strategy will increase projected maize yields by between 48% (LHZ1) and 118% (LHZ2). DSSAT simulations indicate that this adaptation strategy will raise yields between 33% (LHZ1) and 29% (LHZ2).
- The assessment indicates that it is possible to adapt and benefit from the projected changes in climate by making simple adjustments to the existing practices adjusting plant densities and use of fertilizers.
- The assessment highlighted the differential impacts of climate change within a small area and demonstrated the need for site-specific information in designing more appropriate adaptation strategies and in effectively targeting the same.

About the assessment

What evidence climate is changing?

What changes are expected by when?

What impacts these changes will have on agricultural systems and where?

How these impact income and food security of farmers?

How can smallholder farmers adapt?

Way forward

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Introduction

One of the key messages emerging out of the recent IPCC reports is that the climate change is real, happening and will continue to happen for the foreseeable future. The report also estimates with high confidence that the negative impacts on agriculture outweigh the positives which makes adaptation an urgent and pressing challenge. However, adaptation planning requires accurate information about where, when and how the impacts are going to be felt and who will be more vulnerable. Eastern Africa is considered as one of the most vulnerable regions in the world due to its high dependence on agriculture for subsistence, employment and income. Generally the region experiences prolonged and highly destructive droughts covering large areas at least once every decade and more localized events more frequently. The negative impacts of climate are not limited to the years with extreme climatic conditions. Even with normal rainfall, the countries in the region do not produce enough food to meet their needs. Overlaid on this challenging scenario is the dominance of semi-arid to arid climatic conditions which are marginal for crop production, degraded soils, extreme poverty and lack of infrastructure which make the countries in the region highly vulnerable to current and future changes in climate.

There is a rapidly growing literature on vulnerability and adaptation to increased climatic variability and change but most of these assessments are based on statistical and empirical models that fail to account the full range of complex interactions and their effects on agricultural systems. For developing and implementing adaptation programs, more detailed information about how the components of the prevailing farming system such as which crops and varieties are more vulnerable and which management practices are unviable under the predicted climates is needed. However, several problems such as non-availability of downscaled local level climate change projections, lack of information on how the projected changes impact agricultural systems and scarcity of information on how these changes on production and productivity of agriculture translate into economic impacts including food security at household and national levels are constraining such an assessment.

About the assessment

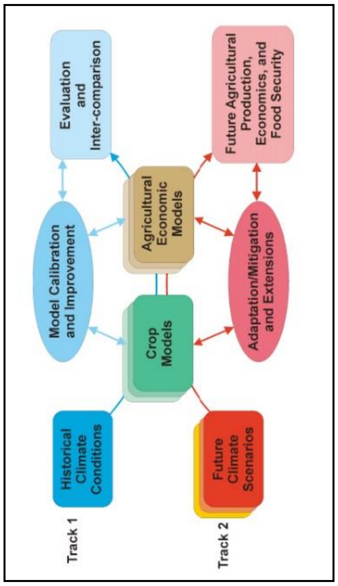

Figure 1: AgMIP approach to assess impacts of climate change

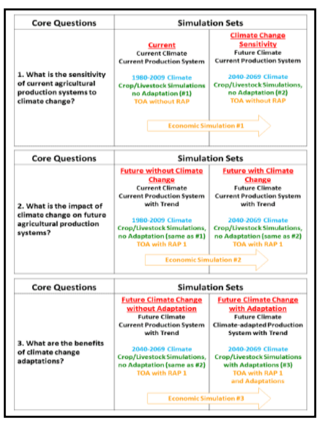

Figure 2: Core questions that this assessment answers

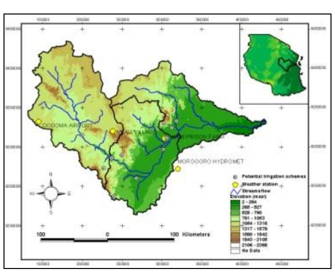

Figure 3: Wami basin

Agricultural Model Inter-comparison and Improvement Project (AgMIP) is a global initiative aimed at making comprehensive assessment of impacts of climate change on agricultural systems by integrating state-of-the-art climate products with crop and economic models (Figure 1). The assessments are structured around a set of questions aimed at better understanding climate sensitivity of locally adopted agricultural systems, assessing impacts of projected changes on the performance of smallholder agricultural systems and options available for adaptation as well as benefits from adaptation (Figure 2).

Key components of this assessment include generating high quality location specific climate change scenarios, defining and parameterizing smallholder systems in a way that captures the complexity and diversity of the systems including the different ways in which the system is managed, assessing the climate sensitivity and evaluating impacts of climate change, developing agricultural futures designated Representative Agricultural Pathways (RAPs) and assessing the socio-economic implications of the expected changes. Using AgMIP protocols and with financial support from the Government of the United Kingdom of Great Britain and Northern Ireland through their Department for International Development (DFID), teams of scientists from Ethiopia, Kenya, Tanzania and Uganda conducted detailed assessment of climate change impacts on agriculture and associated socio-economic vulnerabilities in selected districts in the four countries.

In Tanzania, the assessment was carried out by a multi-disciplinary team consisting of climate, crop and economic modelers from Tanzania Meteorological Agency (TMA), Sokoine University of Agriculture (SUA), Insitute of Rural Development Planning (IRDP). The assessment was conducted on Wami basin which is located between 5°–7°S and 36°–39°E, where it extends from the semi-arid in Dodoma region to the humid inland swamps in Morogoro region to Saadani Village at the coast of Indian Ocean (Figure 3). It covers an area of approximately 43,000 km2, with altitude ranging from 0 meters at the coast to 2260 meters in Ukaguru Mountains (Figure 3). The assessment covered two major livelihoods 1 and 2 which cover the farming systems shaped by semi arid and sub humid agro ecologies, respectively. The farming system of study area is characterized by crop production, livestock keeping as well as off-farm activities. Crop production is undertaken through small scale subsistence farming of an array of crops including maize, rice, sesame, sorghum, millets, legumes; and to less extent large scale commercial crop production such as sugarcane and sisal plantations. Extensive efforts were made to collect the required data on climate, crop and socio-economic conditions as required parameterizing, calibrating and applying climate, crop and economic models. A total *168 farmers were* involved in this assessment having different combinations of soil and crop management. This brief presents the key findings from this assessment.

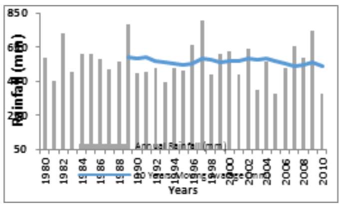

Figure 4: Variability in Annual Rainfall Dodoma

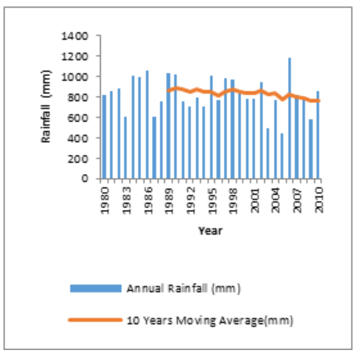

Figure 5: Variability of Annual Rainfall - Morogoro

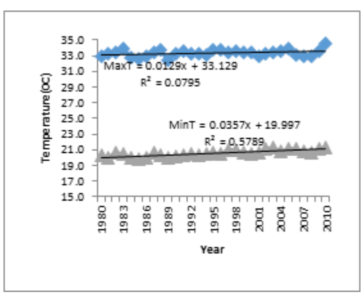

Figure 6: Trend in annual average Maximum and Minimum temperature - Dodoma

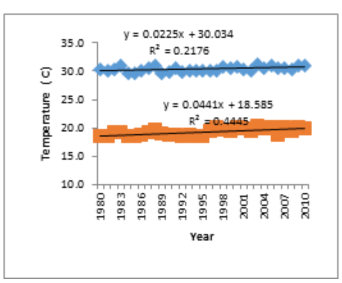

Figure 7: Trend in annual average maximum and minimum temperature - Morogoro

What evidence climate is changing?

A total of 15 weather stations were identified in the Wami basin, of which six stations (Dodoma, Kongwa, Mlali, Wami Prision, Ukaguru Forest, Morogoro Hydromet) had a 30-year measured daily weather data and nine had generated 30-year daily weather data from the AgMIP Hybrid Baseline Climate Datasets. Data were analyzed to characterize the variability and trends in historical climatic conditions. Temporal and spatial variability of rainfall is shown in Figure 4 and 5 for Dodoma and Morogoro, representing livelihood zone 1 (LHZ1) and livelihood 2 (LHZ2), respectively. While no clear trend in the amount and distribution of rainfall was observed (Figure 4 and 5), there are indications that inter-annual variability is increasing. The ten year moving average of coefficient of variation of rainfall for the period 2001-2010 is 1% and 46.1% higher than that during 1980-89 period for Dodoma and Morogoro stations, respectively. Further analyses indicate that the increase in variability of rainfalls is higher in LHZ2 as compared to LHZ1. This is a significant change and will have major impacts on smallholder farms in LHZ2 who mainly depend on crop production for their livelihood where the main food crop grown is maize.

Temperature records show a clear increasing trend in Wami basin on both livelihoods. The analysis is limited to Dodoma and Morogoro stations are representative for LHZ1 and LHZ2, respectively. In both stations observed temperature data for 30 years were used. The analysis indicates that average annual maximum and minimum temperatures are increasing at the rate of 0.013^{0}C and 0.036^{0}C every year for Dodoma station, respectively (Figure 6) representing LHZ1. Figure 7 shows that average annual maximum and minimum temperatures are increasing at the rate of 0.036^{o}C and 0.044^{o}C every year for Morogoro station, respectively representing LHZ2. The increase in minimum temperatures is slightly higher compared to that in maximum temperatures at both stations. Further analysis of data from Morogoro station in LHZ2 confirm these trends. This is a clear endorsement of the fact that the climate in the region is undergoing changes and agricultural systems need to adapt to these changes.

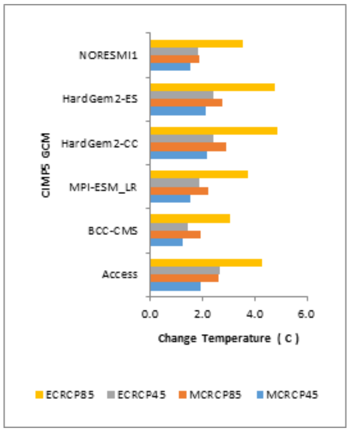

Figure 8: Projected increase in annual maximum temperature (Dodoma)

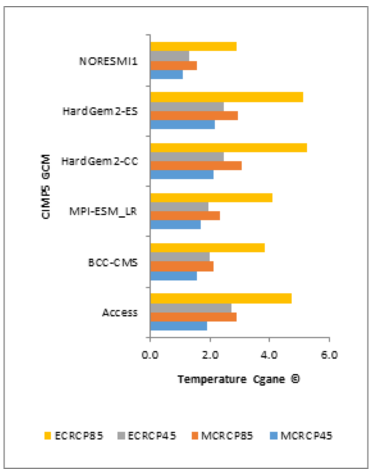

Figure 9: Projected increase in annual minimum temperature (Dodoma)

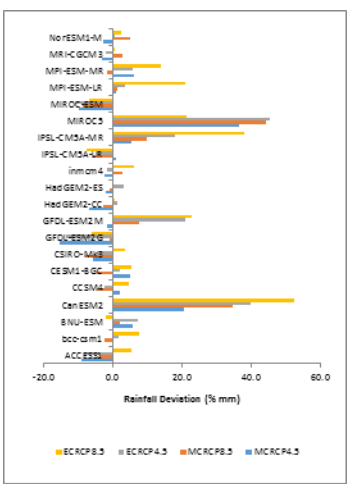

Figure 10: Projected changes in annual rainfall (% deviation from baseline period) Dodoma Station

What changes are expected and by when?

Despite the availability of overwhelming evidence in support of climate change, uncertainty prevails over the precise nature of these changes, especially at local level. Global predictions become less clear as to the magnitude and timing of the changes at national and local levels. Even at the global scale, there will always be uncertainty in predicting future climates, partly due to uncertain levels of future greenhouse gas (GHG) emissions and partly due to differences among GCMs in their sensitivity to GHG emissions. In order to fully account for the uncertainty due to both GHG emissions and GCMs, downscaled location-specific climate change scenarios were developed to mid (2041-2070) and end-century (2071-2100) periods for 20 GCMS from the Coupled Model Inter-comparison Project 5 (CMIP5) under Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the four station which are Dodoma, Kongwa representing LHZ1 and Wami prison and Mlali to represent LHZ2 in Wami river sub-basin.

Though all GCMs predicted a general increase in maximum and minimum temperatures at all locations, there are differences in the magnitude of this increase. Projections by ACCESS1, HadGEM2-CC and HadGEM2-ES tend be higher and NORESM 1, MPI-ESM-LR and BCC-EMS tend to be lower than median values for both maximum and minimum temperatures under all scenarios. The 6 GCMs median values for projected increase in maximum temperature to mid and end century periods are 1.7 and 2.1^{0}C under RCP 4.5 and 2.1 and 4.0^{0}C under RCP 8.5 (Figure 8). In case of minimum temperature, the increase is similar to that in maximum temperature under RCP 4.5 (Figure 9) but under RCP 8.5 the median increase in minimum temperature is higher by 0.1^{0}C to mid-century and by 0.3^{0}C to end-century periods. The highest projected increase towards end-century across all six GCMs is 4.9°C in maximum temperature and 5.3°C in minimum temperature while the lowest projected increase is 1.2°C for maximum temperature and 1.1°C for minimum temperature.

Most GCMs project an increase in rainfall at all locations and under all scenarios (Figure 10). Only three GCMs (GFDL-ESM-2G, MIROC ESM and ACCESS1.0) project a decline in annual rainfall under all scenarios. The median values for the 20 GCMs show the decline of rainfall in mid century period on both RCP 4.5 and RCP 8.5 by -1.1% and -0.8%, respectively. Increase in rainfall towards end century-periods are 1.4 and 5.0% under RCP 4.5 and RCP 8.5, respectively. Among the GCMs, CanESM2 predict highest increase of >50% and GFDL-ESM-2G highest decrease of more than 10%.

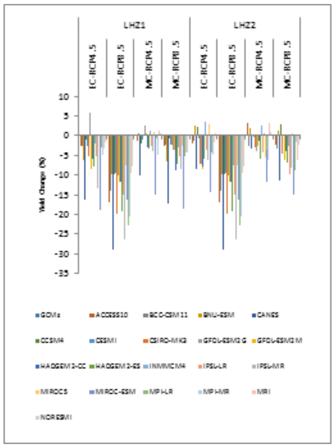

Figure 11: Effect of climate change on maize yields without CO2 effect (APSIM)

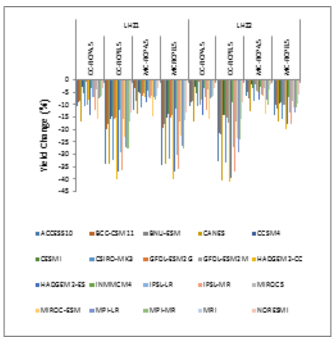

Figure 12 Effect of climate change on maize yields with CO2 effect (DSSAT)

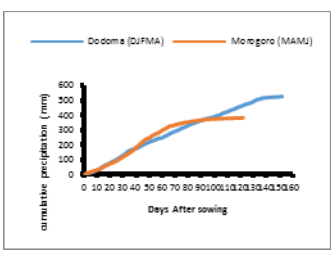

Figure 13: Average cumulative rainfall during LR and SR seasons

What impacts these changes will have on agricultural systems and where?

In order to assess the impacts of climate change on maize production in the two livelihoods, simulation analysis was carried out on 168 farms with diverse and farmer-specific climate, soil, crop and management parameters using calibrated and validated crop models (APSIM and DSSAT) under baseline and climate change scenarios of all combinations of 20 GCMs and RCPs 4.5 and 8.5 for mid and end-century periods.

Simulation results with APSIM which does not account for CO_2 effect indicate that maize yields will increase towards mid-century period under RCP 4.5 scenario by 5% in LHZ1 based on data from GFDL-ESM2G.The increase in yield is also observed in LHZ2 towards mid-century and end century under RCP 4.5 but the increase was 3% for 12 GCMs. The remaining GCMs indicated decline in yield where during end century period under RCP 8.5 scenario, decline ranged from 20 – 30% (Figure 11). DSSAT which accounts for CO_2 fertilization effect indicated that there is no yield increase in all livelihood zones (Figure 12). The predicted decrease in maize yields under climate change scenarios is attributed to temperatures which are higher than the optimal range for maize production. The temperatures are expected to increase by 3.3 to 4.7°C and 3.4 to 5.2°C in LHZ1 and LHZ2 respectively. LHZ2 has two rain seasons where the MAM season takes 122 days whith an evarage seasonal rainfall of 380 mm as compared to LHZ1 with a rainy season starting in December to April with a total of 152 growing days and rainfall amounting to 525 mm (Figure 13).

Impacts of climate change on performance of maize were also influenced by the management adopted such as variety used, planting time, plant population and amount of fertilizer applied and these effects varied between zones. Adverse impacts of climate change were also observed in case of farmers planting late and using low plant population.

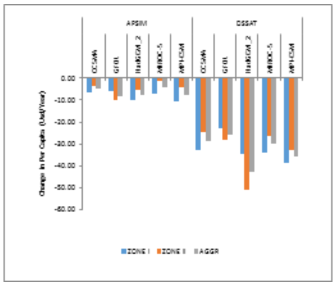

Figure 14: Change in Per capita income

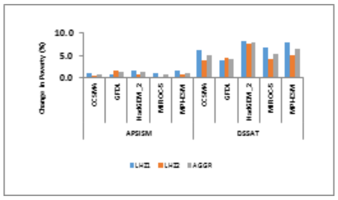

Figure 15: Percentage change in Poverty rates

Table 1: Projected social, economic and biophysical indicators

Indicator	Projected change		
Institutional			
Extension	+	1	Slow
Fertilizers costs	+	5	Mod
Grain prices	+	40	High
Livestock products prices	+	5	High
		Socio-economic	
Household size	No change	-	-
Labor cost	+	2	Mod
Farm size	No change	-	-
Non-Ag income	+	3.5	Very High
Herd size	No change	-	-

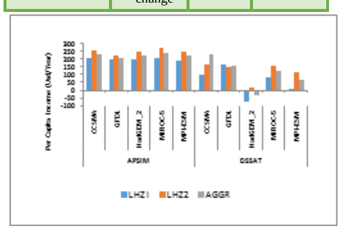

Figure 16: Change in per capita income for future systems (USD/year)

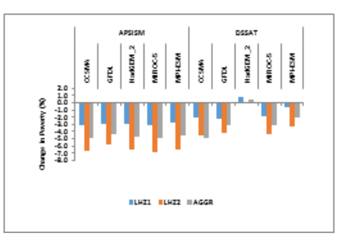

Figure 17: Change in Poverty rates (%) for future systems

How these changes impact income and food security of farmers?

Potential impacts of climate change on the well-being of farmers were assessed using the Trade-off Analysis Multi-Dimensional (TOA-MD) impact assessment tool. The two scenarios tested are a) sensitivity of current agricultural production systems to climate change and b) impact of climate change on future agricultural production systems. Maize production under the climatic conditions predicted by five GCMs (CCSM4, GFDL, HadGEM, MIROC and MPI-ESM) to mid-century under RCP 8.5 as well as estimated impact of climate change on other farm activities through Representative Agricultural Pathways (RAPs) were used in this assessment.

In both livelihoods, all GCMs show that there will be gains from climate change if climate change was to happen now and farmers continue with their current practices. Based on DSSAT simulated yields, the per capita income would decrease by between US$ 23 and 50 per year depending on the GCM while APSIM results are more modest and predict decrease in per capita income between US$ 6 and 11 (Figure 14). This decrease in per capita translates to a modest or no change in poverty level from the current 65.4%. DSSAT model shows that poverty will increase by 3.84% to 8.23% while APSIM estimates between 0.21% and 1.78% (Figure 15).

Impacts of climate change were also assessed by transforming the current production system into the future using technology transfer parameters in the form of RAPs and future output and input prices predicted by global economic models (Table 1). The changes were assessed by comparing two systems: one representing future technology-current climate and the other representing future technology-future climate. Results from this comparison indicate that in that future system, if climate was to change, per capita income would also change and will be higher. DSSAT model four GCM shows increases in climate change of between US$ 12.2 and 235.7 except HardGem which shows decrease in per capita between 32 to 78 US$ while APSIM show gains ranging between US$ 197 4 and 272.6 (Figure 16). This increase in income will have a great implication on poverty of the farmers. The projected poverty level in the future without climate change will be 3.6%. However, with climate change, DSSAT estimates show that poverty levels will decline by between 0.69% and 4.83% for four GCM except HardGem which show that poverty will increase between 0.47 to 0.81%. APSIM predictions for reduction in poverty are lower and range from 2.7% to 6.9% (Figure 17).

How can smallholder farmers adapt?

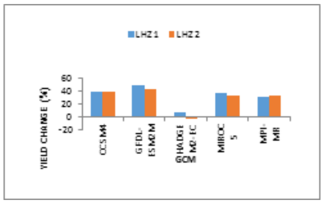

Figure 18: DSSAT simulated Benefits from adoption of adaptation strategy

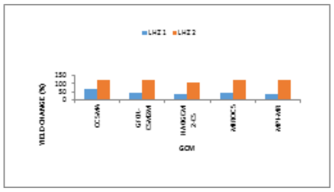

Figure 19 APSIM simulated Benefits from adoption of adaptation strategy

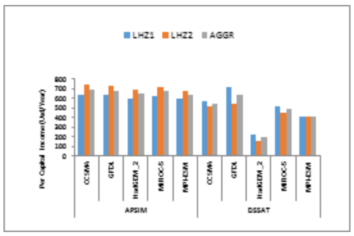

Figure 20 Changes in Per Capita Income (

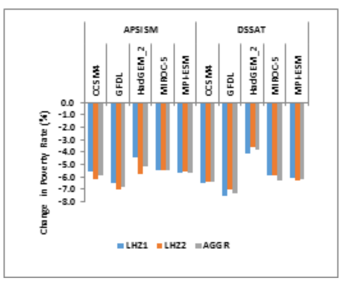

Figure 21: Changes in Poverty Rate after Adaptations)

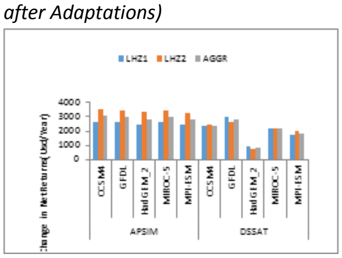

Figure 22: Changes in Net farm Returns with Adaptation

Critical analysis of performance of different varieties and management practices that are currently used by farmers has indicated that it is possible to adapt and make better use of future climatic conditions by adopting some of the available technologies. For both livelihoods fertilizer rate of 60 kg N/ha and plant density of 4 plants/m^2, were used as adaptation strategy.

If the package of practices is adopted by all farmers in the target livelihood zones, it is possible to increase the maize yields significantly even under climate change. The benefits of adoption of proposed strategy as simulated by both DSSAT and APSIM are very similar (Figures 18&19). Model results indicate potential gains in maize yield in all livelihoods under adapted future climates by all GCMs on APSIM. Highest gains are observed in LHZ2 where adopted condition indicates more than 100% yield increase. APSIM simulations show that this adaptation strategy will increase projected maize yields by between 48% (LHZ1) and 118% (LHZ2). DSSAT simulations indicate that this adaptation strategy will raise yields by between 33% (LHZ1) and 29% (LHZ2).

Using TOA-MD, impact of these adaptations to climate change on the indicators of per capita income, net farm returns and poverty were assessed. The indicator for net returns shows that there are substantial increases in net farm returns after the adoption of this package. This is evident in both DSSAT and APSIM simulations (Figure 21). The results indicate that most of the gains in net farm returns from adaptation will be in LHZ2. Per capita income indicator also increases with increase in the net farm returns. Adaptation is also expected to reduce the poverty rates. This is noticeable especially in LHZ2 where poverty levels declines are highest (Figure 22). This is an indication that adaptation to climate change is paramount especially for LHZ2

Way Forward

Available evidence suggests and supports the concerns about climate change and its impacts on agriculture

Climate change offers both risks and opportunities and current efforts to adapt to climate change largely ignored the opportunities

The countries should establish teams of climate, crop and economic researchers who can make use of latest tools and information to make comprehensive assessments of climate change and provide policy and climate adaptation secretariats up to date information on impacts and potential options

The countries should develop appropriate databases that can be integrated and used in these assessments

AgMIP teams and protocols serve as a starting point

This assessment presents evidence of climate change and projects future changes along with accompanying risks and opportunities. It clearly indicates that the predicted changes in climate offer both opportunities and risks. The impacts are expected to be more positive in the environments where current temperatures are below optimal for growing maize (UM2, UM3 and LM 3) while those near or above the optimal range will be impacted negatively (LM4 and LM5). In addition, most GCMs predict an increase in rainfall which will benefit the agricultural systems in the areas where current seasonal rainfall is less than 700 mm. Most national adaptation plans in the region have not fully consider this and as a result put higher emphasis on negative impacts. There is a need to reconsider this approach and if necessary redesign the adaptation strategies in a way that take advantage of positive changes while minimizing the impacts from negative changes.

For designing adaptation strategies that are appropriate to the local conditions, it is essential to conduct this type of comprehensive assessments in all the agro-ecologies of the country taking into consideration the diversity that exists in smallholder farming systems in managing various crop and other enterprises. This assessment demonstrates that much of it can be done using the available data but requires concerted efforts by all relevant national government departments and agencies, donor communities and research organizations. A positive step in this direction will be establishing core teams of scientists from climate, crop and economic fields with skills and capacities to make robust and credible assessments using the new science tools. The members of the AgMIP team and protocols and methods developed by AgMIP can serve as a starting point.

Climate science is fast developing and new and more accurate projections will be available from time to time. Similarly significant advances are being made in improving the crop and economic models to capture the impacts of temperature and CO_2 on crops and other components of the agricultural systems and in translating these impacts into socio-economic impacts. Hence, the teams established must liaise with the global and advanced institutions to take advantage of the latest developments and apply them to refine and re-run the assessments from time to time so that policy and national adaptation programs have latest information.

The analytical framework developed by AgMIP when integrated with the short term forecasts can serve as a powerful tool to predict food security situation and strengthen early warning systems at the national and local levels.

Sources of information

A report on comprehensive assessment of climate change impacts on agricultural systems in Embu County, Kenya

A report assessment of climate change impacts on agricultural systems in the Eastern Africa region

AgMIP web site
http:www.agmip.org

Further Reading

AgMIP methods and protocols

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