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Performance of Dry Land Agricultural Systems under Future Climate Change

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Abstract: *The planet earth, on which we live in communities, is being increasingly 'ruptured' because of human activities; its carrying capacity is under great stress because of demographic pressures. The pressure is especially affecting the people living in the dry areas because of the marginal and fragile nature of the resources they have access to. Dry areas cover more than 40% of the world's land surface and are home to 2.5 billion people one-third of the global population. Superimposed on this is the fact that the neglectful and exploitive use of natural resources has set the train of global climate change in motion.*

The effects of climate change are already being experienced in several parts of the world. Even though the effects of climate change will be felt over all kinds of agricultural production systems, they will be more pronounced in dry land areas where agriculture is totally dependent on rainfall. Simulation output analyses reveal that crop yield will decrease due to climate change and variability in dry-lands, but this can be mitigated in large parts by application of existing knowledge on crop, soil and water management, and by re-targeting and re-deployment of the existing germplasms of the crops in the medium term (2010–2050).

The people 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, there is a 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. This necessitates more investment by international agencies and national governments for supporting the relevant integrated research and sustainable development efforts, with full participation of the target communities. The clock is ticking and the future of the world lies in the collective responsibility and wisdom of all nations on this planet. Changes in agricultural technology and farming systems have had much larger impacts.

1. INTRODUCTION

Dry lands agro-ecosystem is the home to various types of plants, crops and domestic and wild animals. The rainfall is low in amount, erratic, and uneven in distribution, making droughts a common experience. High temperatures and strong winds which characterize these environments result in high evapotranspiration rates, which further exacerbate the limited availability of moisture. In general the ecology is fragile and the environment is unstable. The rainfall is concentrated in a few heavy storms with high intensity. Vegetation is consequently very sparse and generally degraded, leaving large areas of soil unprotected. Apart from in valley bottoms, soils in many dry lands have low organic matter content, are highly eroded and have low fertility.

The dry land areas (40% of world land surface) are home to over 2 billion people, accounting for 35% of the world's population. Some 55% of dry land inhabitants live in rural areas. More than 90% of dry land inhabitants are in the developing world and 70% in rural areas. Approximately half of the poorest people in the world live in the dry areas (Millennium Ecosystem Assessment 2005)

The extent and timing of adoption of new practices by farmers depends on many factors (Knowler and Bradshaw 2007; Pannell et al. 2006). Adaptation to climate change and key factors driving adoption decisions would include the extent to which climate change has already occurred, the expected extent and speed of climate change in future, and the degree of uncertainty about this, the extent to which the practice is already adopted, or will be adopted even in the absence of climate change, the effect of existing or predicted climate change on the relative attractiveness of the practice to farmers; and the extent to which pre-emptive adoption of new practices will be superior or inferior to adaptation subsequent to observed changes.

Table1. *Definition of climate change scenarios*

Scenarios	Definition
S1 – Mild Warming/Drying	1oC warming and 5% drying, at 420 ppm CO2 expected around 2020 with high fossil fuel use
S2 – Moderate Warming/Drying	2oC warming and 10% drying, at 550 ppm CO2 expected around 2050
S3 – Severe Warming/Drying	4oC warming and 25% drying, at 750 ppm CO2 expected around 2100 (A2 SRES)
S4 – Mild Warming/Wetting	1oC warming and 5% wetting, at 420 ppm CO2, to show a possible, but unlikely scenario around 2020

Changes in climate patterns are having most acute effect on people living in the world's dry areas and marginal lands. As these rural communities are largely dependent on agriculture for their livelihoods, it follows that improvements in agricultural research and 'integrated agro-ecosystem' approaches are probably the primary protection from climate related problems. Integrated watershed management is an important tool to mitigate the climate change effects through soil conservation, improved water availability and other secondary benefits. Similarly, conservation agriculture practices under the integrated genetic and natural resource management strategy can help minimize the adverse effects of climate change on dry land agricultural productivity.

1.1. Objectives

To assess the current and future climate change challenges and effects in the dry lands agriculture

To discuss the relevance of the technologies developed, identify best-bet practices to improve the livelihood of the dry land farming communities in the future climate change

2. Literature Review

2.1. Risks and Opportunities for Dry Land Agriculture

Against a backdrop of increasing climate change, a primary challenge for decision makers in the world's dry lands will be helping rural communities to earn a living and produce food securely in a situation where land is degraded, water scarce, and rainfall and temperature patterns increasingly unpredictable. Viable options and interventions exist today. They include using: improved crop varieties and livestock breeds; farming approaches to reduce risk and improve nutrition; making farming for communities living in marginal lands more resilient; and methods for making the best possible use of the scarce water available. Approaches such as diversification of cropping systems, more efficient water management and conservation agriculture can contribute to securing livelihoods for rural people and increasing food security for the dry land countries. Likewise, 'climate smart' strategies and technologies will have an important role to play in helping producers to adapt to changing weather patterns and adopt more sustainable farming methods that protect fragile natural resources.

Projections from the recently launched CGIAR Research Program on Dry land Systems suggest that planned interventions will result in higher and more secure incomes for 87 million people in dry land systems, while improving the productive capacity of natural resources and reducing environmental degradation in nearly 11 billion hectares of dry areas.

2.2. Dry Land Agriculture – a Core Issue for Climate Change

Dry areas cover more than 40% of the world's land surface and are home to over 2 billion people one-third of the global population. Poverty, food insecurity, biodiversity loss, frequent drought and environmental degradation are widespread. In recent decades, food production has fallen significantly in most dry areas, while demand has increased due to high levels of population growth. These areas face several demographic challenges; rapid population growth, large youth populations and among the world's highest unemployment rate.

The global food crisis of 2007/8 and subsequent price hikes have highlighted the danger of policies based on food imports. The dry land areas have a strong reliance on imported food, especially wheat, which is a staple product and which suffers from substantially lower yields than those of many other regions – up to 30% below the global average.

2.3. Future Climate Change and Impacts on Yields in Dry Land Agriculture

Future climate change projections are inherently uncertain, particularly in the long term (IPCC2007). They depend in part on global emissions of greenhouse gases, which in turn depend on economic activity, technology change and climate policy measures over the relevant time frame. The world's climatic system is complex, chaotic and imperfectly understood, so that there is additional uncertainty inherent in the results of global circulation models (GCMs), which are the tools used to predict climate conditional on a range of potential climate-change scenarios (IPCC 2007). Uncertainty is greater about rainfall than about temperatures, and atmospheric CO2 concentration is the least uncertain of these factors (IPCC 2007).

A positive impact of projected temperature increases of up to 1–3 °C on yield has been reported when assuming that temperatures increase by the same degree every day across the growing season. In such a case, a positive yield impact will mainly come from accelerated development and avoidance of maximum temperatures and terminal water stress (Rosenzweig and Parry 1994; Tubiello et al. 2000; van Ittersum et al. 2003). These studies ignored the possible complexities of future temperature changes, in particular the likely increased frequency of extreme temperature events (Battisti and Naylor 2009; Hennessy et al. 2008). The impact of extreme temperatures on crops will depend on the timing, but they have the potential to cause yield reductions of 5 % for each heat-day event during grain filling (Asseng et al. 2011). Thus, if the number of extreme-heat days during grain filling increases, the effect of temperature on crop yields over the coming 50 years is likely to be negative.

2.4. Major Challenges of the Dry Land Production Systems

The major challenges threatening the dry land communities relate to the degradation of the natural resource base, which is leading to soil and vegetation loss, fertility decline, water stress, drying of water resources, lakes and rivers. This degradation is being exacerbated by increasing climate variability and change, with profound impacts on the livelihoods of dry land communities.

The social problems of dry lands include low economic capacity, with limited capital available for investment, which when combined with the environmental degradation results in highly vulnerable production and livelihood systems and thus poverty is pervasive. The other challenges faced by local people include poor health caused by inadequate diets and contaminated water, exacerbated by limited infrastructure. Most importantly, farmers and herders value keeping large numbers of livestock, irrespective of the land and grazing capacity, resulting in overgrazing which is one of major causes of land and natural resources degradation in the dry lands. Additional problems for people living in the dry lands include high levels of crop and livestock diseases and pests also weed infestation of crops, low productivity of grazing lands, lack of improved fodder crops and inadequate livestock water supplies.

2.5. Effects of Climate Change on Crop Growth and Development

ICRISAT studied the effects of climate change on crop growth, development and productivity using crop models (DSSAT and APSIM) under different climate change scenarios. The simulation outputs indicate that climate change in the dry land regions characterized by existing high temperature, will reduce crop productivity by reducing LGP and crop duration (faster crop development, thereby using less natural resources), radiation interception, harvest index, biomass accumulation and increasing water stress in plants as a result of increased evapotranspiration demand due to high temperature. Unless the change in rainfall is substantial, a slight increase or decrease will only have a marginal effect on the crop yields.

2.6. Impact of Climate Change on Dry Land Resources

2.6.1. Water Resources

Water is becoming scarce not only in arid and drought prone areas, but also in regions where rainfall is abundant. Water scarcity concerns the quantity and the quality of the resource available, because degraded water resources are considered unusable for more stringent water uses. The sustainable use of water resource conservation, environmental friendliness, appropriateness of technologies, economic viability and social acceptability of development issues is therefore a priority for agriculture in water-scarce regions (Periera 2003). Some countries are already facing an acute shortage of water (for example, Jordan, Palestine) and others are projected to fall into the same category in the very near future. Water is the single most important commodity, which, if cheaply accessible, can fundamentally alter the potential of a low-rainfall (Fargues et al. 2011).

2.6.2. Land Resources

The livelihoods of more than 900 million people in some 100 countries are now directly and adversely affected by land degradation. Unless the current rate of degradation is slowed and reversed, the food security of humanity will be threatened and the ability of poorer nations to increase their wealth through improved productivity will be impeded. Land degradation can be observed in all agro climatic regions on all continents. Although climatic conditions, such as drought and floods, contribute to degradation, the main causes are human activities. Land degradation is a local problem in a vast number of locations, but it has cumulative effects at regional and global scales. The countries of the developing world, and particularly those in the arid and semi-arid zones, are the most seriously affected. Because agriculture in the poorer countries is the principle employer of labor and generator of income, the effects of land degradation are often disastrous and lead to famine and political turmoil (El-Beltagy 2006).

2.6.3. Crops and Genetic Diversity

Desertification and climate change will greatly impact plant biodiversity. Traditionally, the gene banks in different institutions have collected evaluated and conserved the germplasm of different plants under short and long term storage conditions. The idea is to have valuable and diverse genes of important species conserved for posterity and to provide resources for developing cultivars that might adapt to new eco environments (El-Beltagy 2008). The development of new plant varieties with low-water requirements, better water-use efficiency and the production of drought-tolerant varieties can help increase food production.

Prolonged overgrazing of rangeland and of crop residues in harvested fields weakens and degrades the vegetation, and results in the depletion of plant diversity and reduced biomass production. The latter turn leads to reduced soil organic matter and deterioration of the soil (El-Beltagy 2006).

2.7. Adaptation Measures to Climate Change in Dry Land

2.7.1. Management of Water Resources

There is no doubt that improving the productivity of water in dry areas will continue to be a priority. Efforts to direct new research and the transfer of available technologies to overcome water shortages are very much needed. Coordination of these efforts within an agreed upon framework may enhance their impact. Research and technology framework would include the development of alternative land-use systems and cropping patterns for improved water use that are economically competitive and that respond to changing markets and demands in various agro-ecologies and socioeconomic situations, the development and transfer of alternative irrigation technologies with high water productivity and suitable for irrigation in these alternative land-use systems, developing new guidelines for irrigation scheduling under water-scarce conditions and providing socio-economic incentives for improved water management at the farm level and development of appropriate policies (Oweis et al. 2003).

2.7.2. Rehabilitation of Marginal Lands

Dry land landscapes are particularly vulnerable to degradation because of sparse vegetative cover and the distribution of annual rainfall in a small number of intense storms. The adoption of conservation agricultural practices, such as conservation or zero tillage and crop residue management, green manures and agro-forestry, as well as appropriate crop rotations lessen the risk of accelerated soil erosion from climate change and, in some cases, generate economic benefits that buffer against increased climate risks (Padgham 2009). Over the next 40 years, conservation agricultural practices will have the technical potential to restore more than half of the carbon lost (50 gigatones) from the world’s agricultural soils currently under cultivation. In turn, reducing soil erosion risk and increasing land productivity enhance the strength of the carbon flux from the atmosphere to biomass and from biomass to soils (Rosenzweig et al. 2007).

2.7.3. Crops and Biodiversity Conservation

By far the most significant impact of agriculture on biodiversity is the conversion of highly diverse forests and other natural habitats into much simpler pastures or agricultural systems. An ecological rule of thumb is that a 30% or greater loss of natural vegetation leads to major shifts in wild biodiversity.

Crop diversity conservation and use must be recognized as an essential element of the commitments countries will make for climate change adaptation. It is a prerequisite for the success of all climate change adaptation initiatives, the biological foundation of food security and national economies (McNely et al. 2003 and Masundire 2003).

Today's crop varieties are not adapted to the conditions to which they have never before been exposed. The coldest growing seasons of the future will be hotter than anything experienced in the past. As early as 2030 - fifty years before the situation depicted here maize production will drop by more than 25% unless we move now to help maize adapt to rising temperatures.

2.7.4. Role of Science and Technology

Science and technology can certainly make a huge difference, particularly with the recent availability of new tools and technologies. The new tools, amongst other, include geographic information systems and remote sensing, simulation modeling, biotechnology and genetic engineering, advance artificial intelligence, techniques to harvest renewable energy (solar, wind, second and third generation bio-fuels), new energy-saving techniques to desalinize sea water and transporting it, and nanotechnology (El Beltagy 2008, El Beltagy 1999 and Mendelsohn 2007).

2.8. Future Adaptation to Climate Change in Dry Land Agriculture

2.8.1. Reduce Soil Surface Temperature

Higher temperature is a particular challenge since temperatures limit crop growth. The effects of high temperatures are particularly severe during crop establishment. One effective method to reduce soil surface temperatures is to increase shade. Shade can be produced by developing different forms of agro-forestry. Shade does not only reduce soil surface temperature, but will also reduce water loss from soil and plants thereby making more water available for plant growth. One approach consists of protecting trees that regenerate naturally. Not all trees are desired from a farmers' point of view, but the farmers can select and protect the trees that are most valuable for them.

2.8.2. Effective use of Available Moisture

Once moisture is available for the crop to use, it must be used as effectively as possible. Seed planting depth and timing are carefully considered to place the seed at a depth at which sufficient moisture exists, or where it will exist when seasonal precipitation falls. Farmers tend to use crop varieties which are drought and heat-stress tolerant, (even lower-yielding varieties). Thus the likelihood of a successful crop is hedged if seasonal precipitation fails.

2.8.3. Soil Conservation

The nature of dry land farming makes it particularly susceptible to erosion, especially wind erosion. Some techniques for conserving soil moisture (such as frequent tillage to kill weeds) are at odds with techniques for conserving topsoil. Since healthy topsoil is critical to sustainable dry land agriculture, its preservation is generally considered the most important long-term goal of a dry land farming operation. Erosion control techniques such as wind breaks, reduced tillage or no-till, spreading straw (or other mulch on particularly susceptible ground), and strip farming are used to minimize topsoil loss.

2.8.4. Reduce the time for Plant Establishment; Kick-Start the Plants

Plant establishment is very critical and farmers often have to re sow the seed. Research conducted by the Dry lands Coordination Group shows that it is possible to greatly improve crop establishment by combining the method of seed priming and micro-fertilization. Seed priming consists of soaking the seeds in water for 8 hours prior to sowing and micro-fertilization consists of applying small amount of mineral fertilizer at the time of sowing. Seed priming and microfertilisation can also be combined. Seed priming and micro-fertilization kick-start plant establishment and root development is faster resulting in more drought resistant plants. This ensures a more uniform stand.

2.8.5. Establish Water Harvesting Structures

Water harvesting structures such as planting pits and stone bunds/earth bunds retain water and reduce the risk for crop failure. They will also extend the growing season and increase yields. Use of fertilizer will also be more profitable when combined with water harvesting structures. Organic manure can also be applied to these planting pits thereby improving the soil's chemical and physical conditions enabling better crop establishment.

2.8.6. Using Crop Varieties that are Tolerant to Drought and High Temperatures.

For dry land agriculture to successfully adapt to climate changes and variability there is need to identify climate resilient crops and cultivars for different regions. Through simulation studies using APSIM, Dimes et al. 2008 found that in the semi-arid regions of Zimbabwe, pigeon pea and sorghum were more resilient to the climate change shocks compared to maize and groundnut, mainly due to improved harvest index and water-use efficiency respectively. In semi-arid tropics of Zimbabwe, pigeon pea has a very long duration and grain filling takes place under declining rainfall and increasing water stress. But higher temperatures under climate change will shorten the crop duration of pigeon pea so that it matures when the wet season is still active. Sorghum, on the other hand, experiences greater shortening of the vegetative phase (18%) relative to the grain-filling phase (14%), resulting in increased harvest index (Dimes et al. 2008).

Knowledge and understanding of photoperiod sensitivity, information on the genetic variation for transpiration efficiency, short-duration varieties that escape the terminal drought and high-yielding, disease-resistant varieties will help dry land agriculture adapt to climate change. ICRISAT has been continuously working to identify short duration, heat stress and drought-tolerant lines of its mandate crops of chickpea, groundnut, pigeon pea, pearl millet and sorghum for use in crop improvement with impressive success (Hamidoua et al. 2012; Krishnamurthy et al. 2011).

Further, ICRISAT is engaged in crop improvement work for developing cultivars resistant to abiotic and biotic stresses, keeping in view the threats to dry land agriculture due to current and future climate change. It is hypothesized that the adoption of available improved practices by farmers and retargeting adapted cultivars can help mitigate the climate change effects in the medium term (2010–2050) (Cooper et al. 2009).

2.8.7. Livestock Development Focusing on Fodder Production and Better Fodder Schemes.

Fodder production can easily be doubled as a result of the improved crop management methods described above. The fodder's quality can also be improved by harvesting earlier and using more legumes as fodder. ILRI has also developed an improved fodder ration that improves the protein content and reduces waste. Increased fodder production will make it possible for the farmer to store more fodder which can be used in crisis situations. An increase in crop production will reduce the pressure on pastures since there will be less need for expanding the cultivated area. This will also benefit passing pastoralists.

2.8.8. Responsive Agronomic Practices to Cope with Climate Change and Variability

Under the climate change scenarios, many of the conventional cultivation practices and strategies may no longer be relevant. Therefore, there is a need to recommend technologies to the farmers which respond well to climate change effects and give greater resilience against such shocks. Growing early maturing, photo-insensitive, high tillering cultivars with optimal root traits and tolerant to abiotic and biotic stresses; conservation agriculture; mulching with crop residues; planting more seedling per hill for heat stress; better soil nutrient and water management, moisture conservation for late onset of monsoon and life-saving irrigation with stored rainwater for mid-season drought. In Zimbabwe, precision conservation agriculture has consistently increased average cereal yields by 50–200% in more than 40,000 farm households (with the yield increase varying with rainfall regime, soil type and fertility, and market access) (Twomlow et al. 2008).

Table 2 Improved agronomic Practices in crop yield increase in dry lands

Agronomic Practice	Impact on output in Dry lands of Africa	Remarks
Optimum time of planting	Up to 50% increase output in dry areas is possible.	Considerable research has already been done for dry areas of Africa.
Improved spatial arrangements and plant populations	Up to 20% increase in yields.	Only a well-coordinated extension effort is required.
Improved field preparation and tillage practices	Up to 30% in drier areas and areas with "difficult" soils in the humid zone.	A lot of as yet unfinished research is being undertaken

Use of the best variety available	Up to 30% in large areas	Development is very fast
Better fertilizer In Africa less satisfactory.	Up to 50% in large areas.	In Asia, there is a good database on fertilizer response.
Better weed control	Up to 40% in many areas.	Can very easily be improved.
Better pests and disease control	Up to 30% almost everywhere	Much more research is required

Source: Kidane et al. Ethiopian Institute of Agricultural Research, 2005

2.8.9. Watershed Management: a Growth Engine for Dry Lands

It has been predicted that most of the rainfall will now occur in the form of high-intensity short-duration rain events due to global climate change (IPCC 2007). It is imperative to harvest the run-off water to protect the crops against moisture stress as well as to avoid floods in downstream areas. Integrated watershed management will play an important role in soil and water conservation, efficient use of rainwater, improved crop and livestock productivity and improved living standard of people at large, especially in dry and marginally fertile land areas.

The new integrated community watershed model provides technological options for management of run-off water, *ex situ* water harvesting for lifesaving irrigation, *in situ* conservation of rainwater for improved soil moisture content, groundwater recharging, developing grassed waterway systems, appropriate nutrient and soil management practices, and improved crop production technology and appropriate farming systems with income-generating micro-enterprises for improving livelihoods, while protecting the environment (Wani et al. 2002; Wani et al. 2006 and Sreedevi et al. 2004).

3. Summary And Conclusion

In light of what has been presented above, the way forward for enhancing the resilience of dry area inhabitants to cope with the challenges of climate change includes several essential elements. These include better assessment of climate change scenarios by carrying out assessments at the regional, national and local levels to navigate through and across scales, rapid transition to inter sectoral thinking, institution building, planning and policy making for responsible and sustainable agriculture, coping with uncertainty, recognizing that there will be a shifting of the baseline as further assessment of climate change is done, essential increased investment in research and information systems.

The overall impact of past climate change on crop yields has been minimal, and for reasons other than climate change, farmers have to adopt many of the practices recommended for future climate change. Four broad roles for science that may be relevant to climate adaptation in agriculture are promoting adoption of existing technologies, developing new technologies, measuring and predicting climate change, and disseminating such measurements and predictions.

In dry land areas where resources such as soil, water and fertility status are low and where the length of growing period is usually short and variable, the timeliness and precision of field operations is important for increased production and productivity. Hence, as indicate earlier, the genetic potential of crops can only be realized if both improved varieties and management practices are integrated and implemented. This is an extremely important issue in the context of adaptation to climate change and variability.

Scientists’ roles in developing and disseminating information that may assist farmers with their decision making about adaptation to climate change. A clear role for the science community is to share their current knowledge, uncertainties and future knowledge gains with the farming community to help them to understand climate change and, potentially,

prepare to adapt to it. Again, there are several distinct areas of research that could be pursued. As illustrated earlier, this research can provide insights that are relevant to consideration of current and/or future adaptation strategies for farmers, increasing confidence about whether adaptation is currently warranted.

As the dry lands will become increasingly important to ensure the food security of the nations in the future, there is need to develop climate change mitigation and adaptation strategies along with restoring the natural resource base, which at present is critically degraded in the dry lands. This is also important for the livelihood security of millions of the poor people who live in the arid and semiarid regions. Integrated watershed management holds great promise to minimize the climate change effects on dry land agriculture through soil and water conservation, productivity enhancement, promotion of agro forestry, and income-generation activities through value addition and other off-farm activities.

When carefully managed, climate smart initiatives can produce tangible benefits to rural communities and the land they depend on, making it more resilient when faced with climate swings. Promising technologies to combat this unpredictable situation include crop varieties adapted to perform well under climate change factors, technology tools, devices for farmers and systems for delivering targeted timing and doses of fertilizer and irrigation.

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