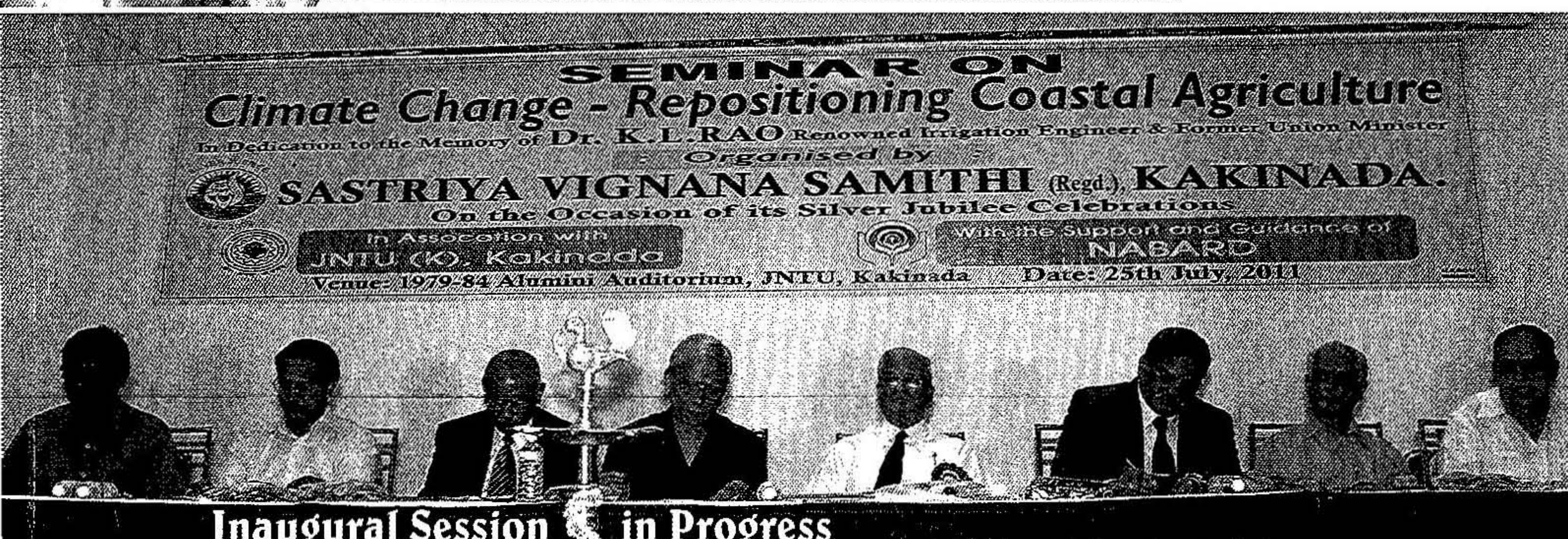
Proceedings of the Seminar on
"CLIMATE CHANGE - REPOSITIONING COASTAL AGRICULTURE"

on 25th July 2011 at Alumni Auditorium, JNTU, KAKINADA

Dedicated to the memory of
Renowned Irrigation Engineer and Former Union Minister Dr. K.L. Rao



Inaugural Session in Progress

Organised by
SASTRIYA VIGNANA SAMITHI (Regd.), KAKINADA

on the occasion of its SILVER JUBILEE CELEBRATIONS
in association with Jawaharlal Nehru Technological University, Kakinada
with support & Guidance of NABARD

SILVER JUBILEE NUMBER

RESILIENT DRYLAND SYSTEMS FOR REDUCING VULNERABILITY TO DROUGHT AND CLIMATE CHANGE WHILE INCREASING CROP DIVERSITY AND VALUE: THE ICRISAT EXPERIENCE

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The impact of escalating human activity on the greenhouse gas emission, global warming and changes in global climate patterns and its consequent impacts on life and global phenomena is among the most debated issues of the first decade of the 21st century. It is being discussed worldwide at various levels in the society - from global, regional and national institutions through to the development agencies and down to private citizens and to farmers in the developing world.

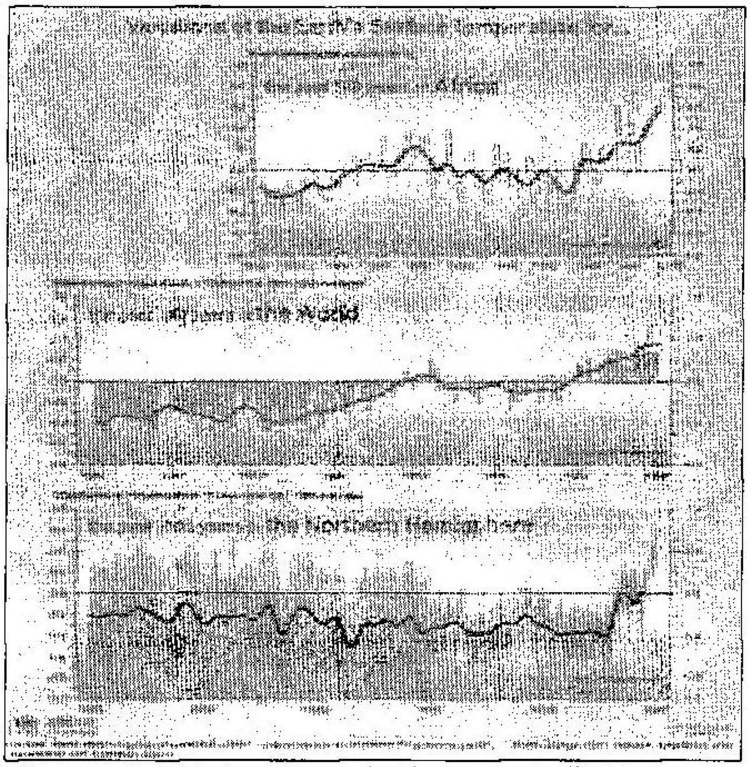

Figure 1. Temperature changes in Africa, the whole world and the Northern hemisphere.

In 2002, the Intergovernmental Panel for Climate Change (IPCC) provided a strong evidence for an accelerated global warming (Figure 1). In Paris in February 2007, the most recent assessment was released, which dispersed beyond any reasonable doubts, the link between human activity and global warming, although the final outcome and impact of the climate change still remains uncertain. (IPCC 2007). The projected climate change for India is given in Table 1.

Table1. IPCC Projected Climate Changes for India

Year	Season	Increase in Temperature, °C		Change in Rainfall, %	
		Lowest	Highest	Lowest	Highest
2020s	*Rabi*	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.12	1.81	5.10
2050s	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

Source : Lal, 2001.

In the intervening period, many key investors and stakeholders in agricultural development in the Third World have recognized that whilst the exact nature and extent of the impacts of climate change on temperature and rainfall distribution patterns remain uncertain, it is the poor and vulnerable who will be the most susceptible to the changes in climate. This is especially true for those communities who live in the dryland areas and who rely largely or totally on dryland agriculture for their livelihoods. It is they who are also currently most vulnerable to the existing rainfall variability and climatic shocks. This necessitates farmers and farming practices in dryland areas to adapt to the future predicted climate change, the effects of which have already started to be experienced in one or other parts of the country.

Dryland agriculture and global climate change:

India has about 47 million ha of dry lands out of 108 million ha of total rain fed area. Dry lands contribute 42% of the total food grain production of the country. These areas produce 75% of pulses and more than 90% of sorghum, millet, groundnut and pulses from the arid and semi-arid regions. Thus, dry lands make significant contribution to the food and nutritional security of the country. In future, the significance of dryland in national food security will further increase due to continuous population pressure and competition of land for non-agricultural uses. This highlights the need to develop climate change mitigation and adaptation strategies for the dryland regions.

It has been projected that even though the effects of climate change will be felt over all kinds of agricultural production systems; its effects will be more pronounced in dryland areas where agriculture is totally dependent on rainfall. If climatic change is accompanied by an increase in climate variability, crop production in dryland regions will experience increased risk of crop failure. This vulnerability has been demonstrated by the devastating effects of recent flooding and prolonged droughts during the twentieth century and the first decade of the 21^{st} century in the dryland areas.

The ICRISAT studied the effects of climate change on crop growth, development and productivity using crop models (DSSAT and APSIM) under different climate change scenarios. Global warming associated with the increase in temperature in the dryland regions characterized by existing high temperature will reduce crop productivity by reducing the length of growing period (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 ET demand due to high temperature. Unless the change in rainfall is substantial, slight increase or decrease in rainfall will have a marginal effect on crop yields. However, increase in CO_2 concentration will have beneficial effects on crops, especially the legumes (C3 species) by increasing photosynthesis rate. Crop simulation analysis for kharif sorghum using the DSSAT at Parbhani in Maharashtra showed that a temperature increase of 3.3 °C, which is expected to increase by the end of this century, will on an average reduce the crop yield under good management by 27 %. However, the effect of 11% increase in rainfall will be marginal (Fig. 2). Despite a variable response across seasons to increase in temperature, an average yield reduction of groundnut crop at Anantapur will be about 38 %, and an increase in rainfall will benefit the crop marginally (Fig. 3). Considering the impacts of increase in temperature and CO2 concentration, the yield reduction of the rain-fed crops across a few selected locations in India are simulated to be from 22 to 50 % for kharif sorghum, 33 to 51% for pearl millet, 23 to 29 % for groundnut, 8-11% for pigeonpea and 7 % for chickpea at Nandyal and Akola (Wani et al., 2009). Because of the current low temperatures during the post-rainy season at Guna (Madhya Pradesh), climate change is expected to increase the chickpea yield by about 9 %. However, the climate change impact at the current low levels of management of crops would be marginal. This means that as we improve the management of crops to achieve higher crop yields to achieve food security, the impact of the climate change will become significant.

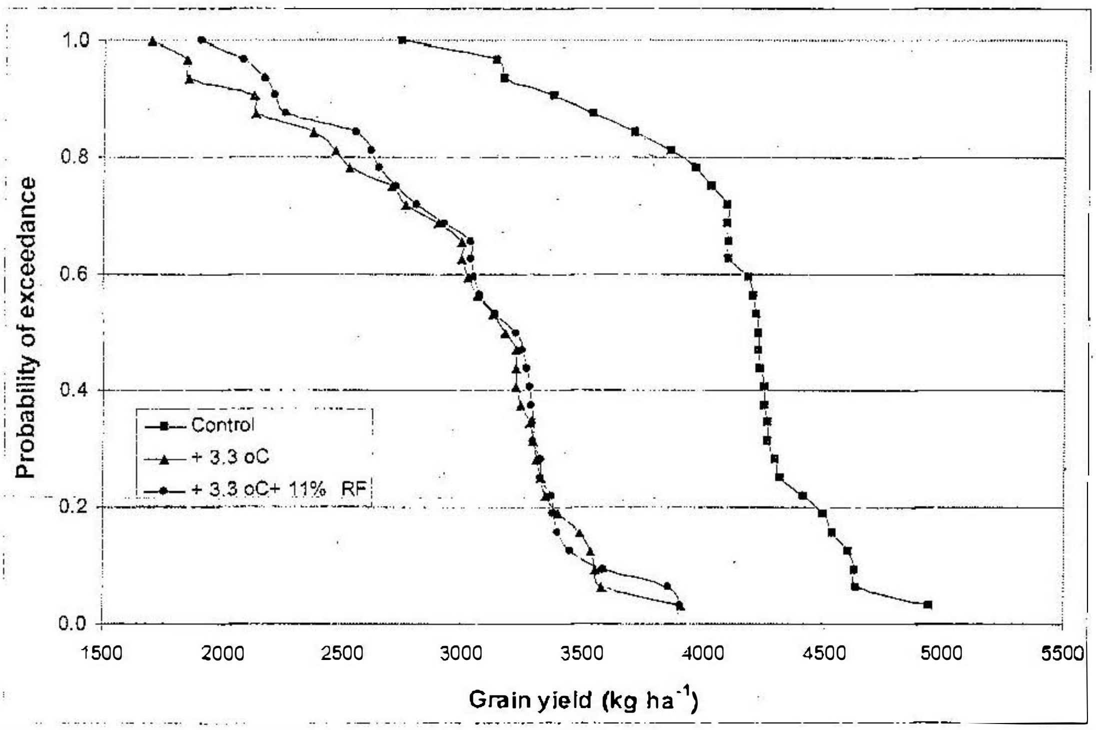

Figure 2. Probability distribution of the Kharif sorghum yield under climate change at Parbhani, Maharashtra. Source: Wani et al.(2009)

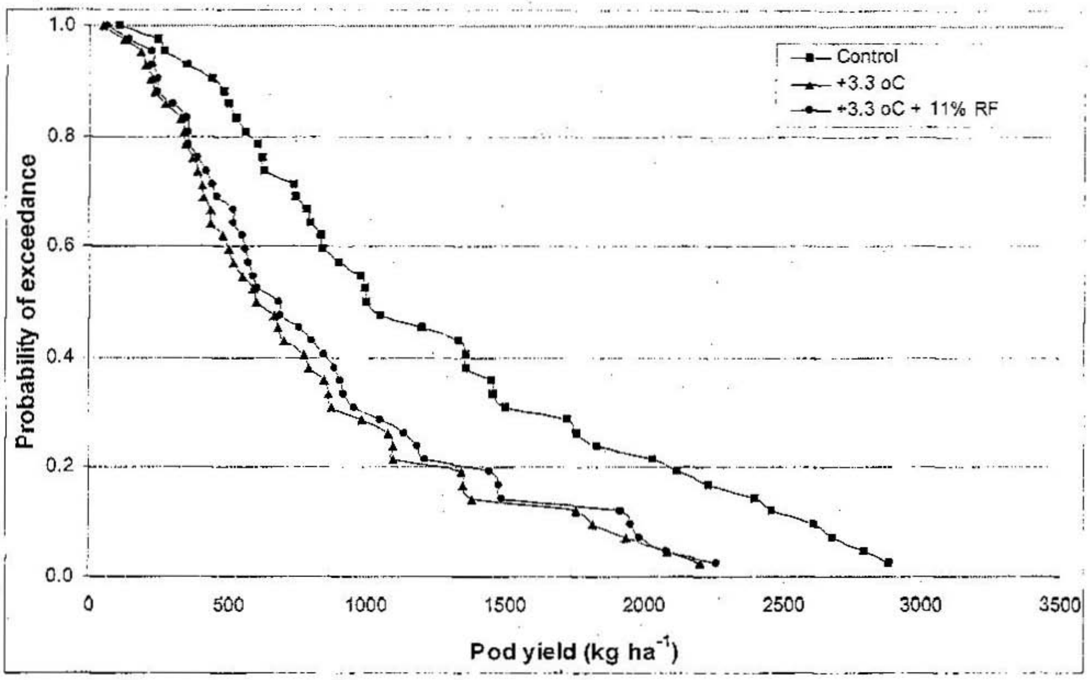

Figure 3. Probability distribution of groundnut yield under climate change at Anantapur, Andhra Pradesh. Source: Wani et al.(2009)

Adaptation strategies to climate change:

In the changing climate scenario along with increasing population pressure and highly degrading resource base (land degradation and water scarcity), the current way of crop production in dry lands is no longer an option. To ensure food security for a vast population, suitable long-term coping strategies need to be developed to adapt dryland agriculture to the impacts of climate change in the near future. Farmers in particular and the society in general have always attempted to adopt to climatic stresses by restoring to mixed cropping, changing varieties and planting times and by diversifying their sources of income. In future, such adaptation strategies would need to be considered along with the changing demand due to globalization and population increase and income growth, as well as the socio-economic and environmental consequences of possible adaptation options.

For many poor countries that are highly vulnerable to effects of climate change, understanding farmers' responses to climatic variation is crucial in designing appropriate coping strategies to climate change. The impact can be reduced through lessening the human impacts on the atmosphere and the climate through emission reductions and adapting to live with a changing climate before the results of mitigation can begin to appear.

Advancing a 'Hypothesis of Hope':

It is hypothesized that "with medium term (2010-2050) ICRISAT is well placed to help farmers mitigate the challenges and exploit the opportunities that are posed by climate change through: (i) the application of existing knowledge on crop, soil and water management innovations and (ii) the re-deployment and re-targeting of the existing germplasm of its mandate crops. Climate change will modify the length of the growing period across the regions of interest, but that this can in large part be mitigated by the re-targeting and re-deployment of the existing germplasm of the crops and by managing rainwater through water conservation and harvesting.

Schematic framework for testing the hypothesis:

Current Climate Yield Gap: Column 1 (Fig. 4) in the schematic represents yields that farmers are getting under their current and relatively low input management. Column 5 represents the yields that farmers could get through the adoption of current simple and affordable recommendations for improvements in variety choice and crop, soil, nutrient and water management practices. This is the yield gap that ICRISAT is currently addressing.

Yield Gap 1: Column 2 (Fig. 4) represents the marginally decreased yields that farmers would get under climate change if they were to continue using the same low-input system. We have shown that under such low input systems, factors other than climate change continue to provide the overriding constraint. Column 3 represents the yields that farmers could get, even under climate change, if they adopted current improved practice recommendations. This is the yield gap that ICRISAT is and will continue to address through our work to develop, scale up and scale out enhanced crop, soil, and nutrient and water management options for farmers in the dryland areas.

Yield Gap 2: Column 4 (Fig. 4) represents the yields that farmers could get under climate change if they were to adopt current improved practice recommendations together with developed cultivars better adapted to a warmer world. Within the scope of the ex-ante analyses that we have done so far, we consider better adaptation solely constitute varieties whose maturity length is better suited to growing in a warmer world. We recognize that other factors such possible changes in rainfall patterns and in the distribution of pests and diseases will also have to be considered. This is the yield gap that ICRISAT will be addressing through our work to develop and deliver improved crop varieties with enhanced performance under high CO_2 concentrations, high temperatures and erratic rainfall conditions for farmers in the semi-arid tropics.

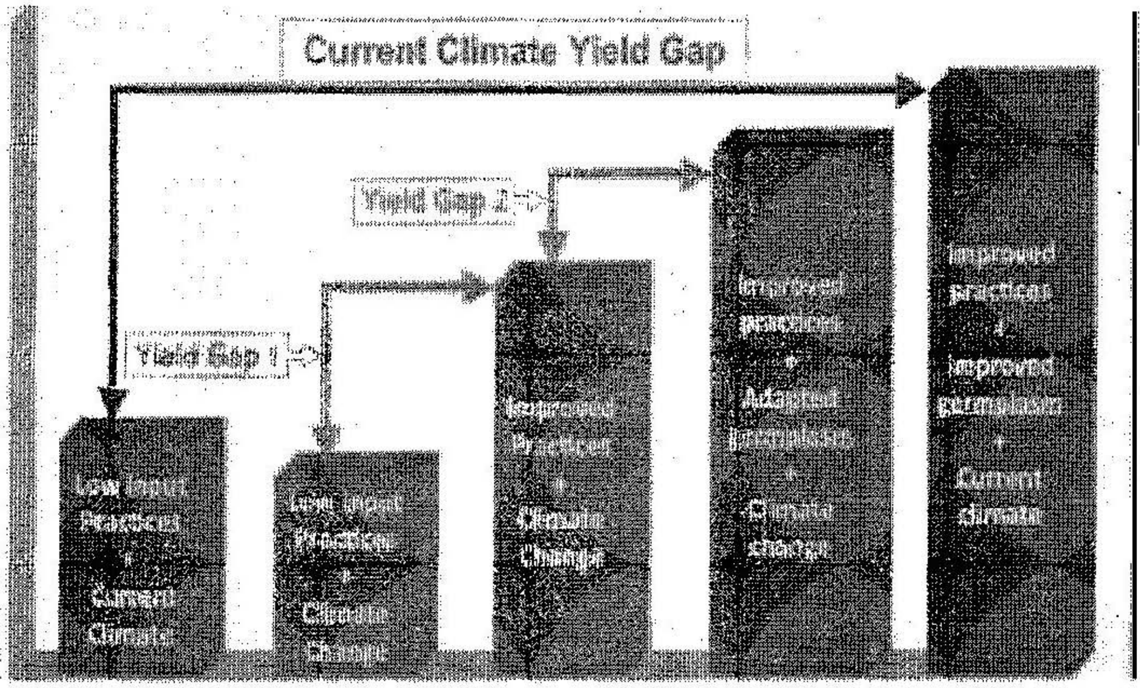

Figure **4**.Hypothesis of Hope" schematic framework
Source: Wani et al. (2009)

Sorghum Production in India: a case study for cereals

Sorghum is a very widely grown crop in the dryland areas of India, but currently yields remain low due to lower than recommended use of nitrogen and phosphorous fertilizers. Sorghum (Var. CSV15) is widely grown and at Aurangabad reaches maturity 105 days after emergence. Based on the above, the following scenarios were simulated using DSSAT and long-term daily climate data from Aurangabad.

- Column 1. Sorghum (Var. CSV15) planted between June 1st and July 20th with 18 kg N + 20 kg P ha^{-1} as DAP at sowing and 15 kg N ha^{-1} as urea at 40 days after sowing This represents current low input farming.

- Column 2. Low input agriculture as above but under a climate change scenario of an increase in temperature of 3^{O}C.

- Column 5. Improved practice under current climate comprised sowing CSV15 within the same planting window, but with the recommended application of fertilizer namely 40 kg N + 40 kg P ha^{-1} as DAP at sowing and 40 kg N ha^{-1} as urea at 40 days after sowing.

- Column 3. Improved practice as above under an increased temperature of +3^{O}C.

- Column 4. Improved practice under climate change as above, but with an adapted longer duration sorghum variety that matures in 119 days under current conditions at Aurangabad (such as Brandes, taken from the DSSAT sorghum data base), but which matures in 103 days under the warmer climate change scenario simulated.

The outputs of these simulations are presented in Figure 5.

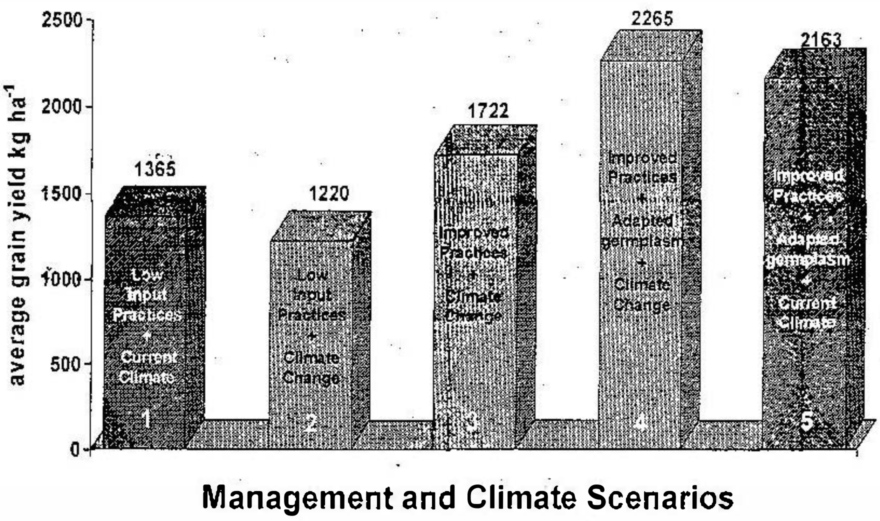

Figure 5. Sorghum yield (kg/ha) simulations (DSSAT) at Aurangabad, India, 1955 to 1983

Source: Cooper et al. (2009)

A temperature increases of +3^{O}C had very little impact (145 kg/ha reduction) on the sorghum yield under low input fertilizer use as nutrient limitation remained a strongly limiting factor. Even under climate change, the adoption of improved fertilizer use (column 3) resulted in yield gains of 357 kg/ha over what farmers are currently getting under low input practices and under today's climatic conditions (column 1). Perhaps the most notable result in this case is that growing a longer duration variety (Brandes), better suited to grow in a warmer world (column 4), resulted in farmers being able to achieve yields 5% higher than they could under "improved practices" with today's climate (column 5).

The outputs from the above simulation work support the hypothesis that through the application of existing knowledge on crop, soil and water management innovations and the re-deployment and re-targeting of the existing germplasm of its mandate crops, the ICRISAT is well in position to help farmers mitigate and adapt to the climate change effects in the medium term (2010-2050). However, it is recognized that this and other simulation tests done for other locations hardly scratch the surface of the work that remains to be done, both in our simulation work and the more pragmatic testing of our hypothesis in the field. We need to enhance and expand the value of our crop growth simulation work with the APSIM and DSSAT through undertaking an extensive field-based exercise that results in the proper phenological and physiological characterization of the sub-sets of our germplasm so that we can fully exploit the genetic diversity we have at hand through the development of new and the re-deployment of existing cultivars, both in our simulations and in our field research. The above 'genetic-based' field research should be complemented by elaborate calibration of the DSSAT and APSIM for wide range of soil, fertility, water and crop management practices that we believe hold hope both now and for the future.

Use of adapted/improved cultivars:

For adapting the dryland agriculture successfully 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 pigeonpea 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. A more favourable soil water balance for the pigeonpea explains such results. Under the current uni-modal rainfall conditions (and latitude), the crop has a very long duration such that grain filling takes place under declining rainfall and increasing water stress. Higher temperatures under climate change will shorten the crop duration so that it matures when the wet season is still active. This is particularly true for the duration of the grain filling period, which is reduced by 31% on average. Sorghum, on the other hand, experiences greater shortening of the vegetative phase (18%) relative to the grain filling phase (14%), resulting in increased HI. As the increase in temperature will reduce the crop duration due to hastening of crop development, leading to yield losses due to reduced use of solar radiation and low biomass accumulation, the one easy and readily available adaptation strategy to climate change is to retarget the current long duration germplasm. The crop model outputs show that in the warmer regions of India (northern, western and some parts of southern India), where in spite of increase in CO_2 and rainfall the detrimental effects of increase in temperature are large, there is need to have cultivars that are temperature tolerant, and will fit well in the water availability period. Whereas in the relatively cooler regions where the beneficial effects of increase in CO_2 and rainfall are greater in terms of biomass production, there will be need of cultivars having even greater harvest index to take advantage of climate change. In climate change adaptation aspects, ICRISAT already has on hand climate ready crops that are adapted to heat and high soil temperatures. Knowledge and understanding of photoperiod-sensitive flowering, information on the genetic variation for transpiration efficiency, short duration varieties that escape the terminal drought and high yielding disease resistant varieties for e.g. in chickpea ICCV 96029 (super early 75-80 days), ICCV 2 (extra early 85-90 days) and KAK 2 (early 90-95 days) will help to adapt dryland agriculture to climate change.

Integrated watershed management to enhance productivity and resilience:

The integrated watershed development approach could be one of the options for reducing the climate change impact by increasing water and nutrient use efficiencies, reducing land degradation and reducing the risk through farming systems' diversification in the rain-fed agriculture.

A consortium model proposed by the ICRISAT for community watershed management espouses the principles of collective action, convergence, cooperation and capacity building (4Cs) with technical backstopping by a consortium of institutions to address the issues of equity, efficiency, economics and environment (4Es). The new integrated community watershed model provides technological options for management of runoff water harvesting, waterway systems, in-situ conservation of rainwater for groundwater recharging and supplemental irrigation, appropriate nutrient and soil management practices, crop production technology and appropriate farming systems with income-generating micro-enterprises for improving livelihoods while protecting the environment (Wani et al. 2002, 2006, Sreedevi et al. 2004). The water alone cannot improve the productivity of crops in the dry land areas, and proper soil, crop, nutrient and pest management options are essential to improve productivity and impart climate resilience to dryland areas.

ICRISAT experience on the watershed management in India is one such example. The combined effects of enhanced crop tolerance to drought, integrated management of land and water resources and improved water productivity has reduced the vulnerability to climate shocks and also improved productivity. This is illustrated in the Kothapally village. Integrated watershed management has contributed to improving the resilience of agricultural incomes despite the high incidence of drought. While drought induced shocks reduced the average share of agricultural income (as % of the total household income) in nearby non-project village from 44 to 12%, this share remained unchanged at about 36 % in the adjoining watershed project village of Kothapally (Shiferaw et al. 2006).

Improving water availability in the watersheds was attributed to an efficient management of rainwater and in-situ conservation, establishment of WHS and improved groundwater levels. Supplemental irrigation, one of the climate change adaptation strategy can play a very important role in reducing the risk of crop failures due to and in optimizing the productivity in the dryland areas.

Meta-analysis of 311 watershed case studies from different agro-eco regions in India revealed that watershed programs benefited farmers through enhanced irrigated areas by 33.5 %, increased cropping intensity by 63%, reducing soil loss to 0.8 t ha-1 and runoff to 13% and improved groundwater availability. Economically, the watershed programs were beneficial and viable with a benefit – cost ratio of 1:2.14 and the internal rate of return of 22 % (Joshi et al. 2005). However, about 65% of the case studies showed below average performance. Better performance of watersheds was realized in the rainfall regime of 700-1000 mm. There is need to develop technologies for the areas falling in the rainfall regime of < 700 mm and >1000 mm.

The effectiveness of improved watershed technologies was evident in reducing runoff volume, peak runoff rate and soil loss, and improving groundwater recharge. This is particularly significant in the Tad Fa watershed where interventions such as contour cultivation at mid-slopes, vegetative bunds planted with Vetiver, fruit trees grown on steep slopes and relay cropping with rice bean reduced the seasonal runoff to less than half (194 mm) and soil loss less than 1/7th (4.21 t ha-1) as compared to the conventional system (473 mm runoff and soil loss 31.2 t ha-1). This holds true with peak runoff rate where the reduction is approximately one-third.

Using early maturing varieties, application of P fertilizer at planting for late onset of monsoon; high tillering cultivars and optimal root traits for mid-season drought; delay sowing , P fertilizer application, water harvesting and run off control for early drought; early maturing traits for terminal drought; heat tolerance traits, crop residue management and large number of seedling per planting hill for increased temperature; better soil nutrient management to promote positive effect of increased CO_2 level are few ICRISAT strategies to over come the climate change as well variability on rain-fed production (Cooper et al. 2009). In addition, emphasis should be given for improving soil organic matter content in soil, which is an important driving force for supporting biological activity in soil. Besides, organic matter by improving water holding capacity of soils can minimise the climate change effects through enhanced length of the growing period. Management practices that augment soil organic matter and maintain at a threshold level are needed. Farm bunds could be productively used for growing nitrogen-fixing shrubs and trees to generate nitrogen-rich lopping. For example, growing *Glyricidia sepium* at a close spacing of 75 cm on farm bunds could provide 28-30 kg nitrogen per ha in addition to valuable organic matter. Also, large quantities of farm residues and other organic wastes could be converted into valuable source of plant nutrients and organic matter through vermicomposting (Wani et al. 2005).

Conservation agriculture, which basically consists of zero/minimum tillage, soil cover through crop residues or cover crops and suitable crop rotations is being promoted as another strategy for climate change mitigation and adaptation as well as sustainable crop production through soil and water conservation and other associated ecological benefits. At CRISAT we have observed encouraging results of conservation agriculture on crop productivity and soil qualities along with considerable reduction in runoff, peak runoff rate and soil loss.

ICRISAT evaluated the effects that water conservation innovations could have in mitigating the impact that increased temperatures have in reducing the length of growing period. Cooper et al. (2009) simulated the length of growing period at Makindu, Kenya under three scenarios, namely, (i) current climate with no water conservation which represents current practice (blue line in Fig. 6), (ii) current climate + $3^{O}C$ with no water conservation which represents recommended practices (green line in Fig. 6) and (iii) current climate + $3^{O}C$ + mulching for water conservation (red line in Fig. 6). The average LGP at Makindu, Kenya under current climate and current soil management is 110 days, but this is reduced by 8%, with a $3^{O}C$ rise in temperature, to 101 days. However, the application of maize residue mulch under the climate change scenario in fact raised the average LGP to 113 days, 3 days longer than under current climate conditions. When the mulch was applied, under a $3^{O}C$ temperature increase, the LGP was lower only in the 30% of the most favourable than that experienced today seasons. Thus water conservation measures like mulching have important beneficial impacts on water storage in the soil profile and hence the LGP not only under current climate conditions , they can also play a major role in helping to manage and ameliorate the impact of future climate change on the LGP (Fig.6).

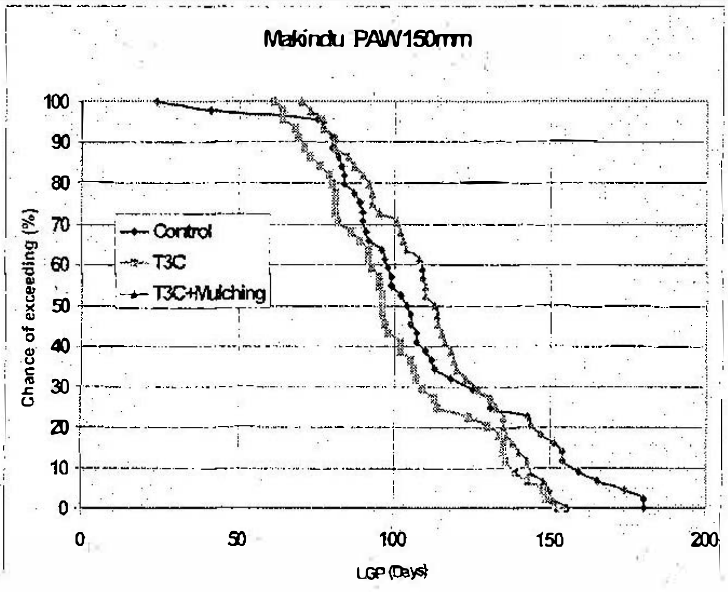

Figure 6. The effects of mulching on ameliorating the impact of climate change on LGP. Makindu, Kenya. Source: Cooper et al. (2009)

Crop diversification and value addition:

Crop intensification and diversification with high-value crops is one example that has helped households to achieve production of basic staples and surplus for modest incomes in model watersheds adopted by the ICRISAT. With technical support from the consortium, the farming system was intensified from rice and rape seed to tending livestock (pig raising) and growing horticultural crops (fruit trees like *Ziziphus*; vegetables like beans, peas and sweet potato) and groundnut. Crop diversification options including crops, multipurpose tree species, medicinal and aromatic plants, etc. may be of great help to adapt dryland agriculture to climate change and variability. There is need to identify and test different locally suitable crop diversification options for different agro-ecological regions. ICRISAT along with its consortium partners is engaged to identify resilient crops and cropping systems through its watershed program in different parts of the country.

The NutriPlus Knowledge (NPK) program of the ICRISAT's Agribusiness and Innovation Platform (AIP) is engaged in research and development to deliver innovative value-added food products from the dryland crops.The NPK also works towards promoting these products and technologies among the entrepreneurs, food industry and consumers. Development and commercialization of such value-added products and related entrepreneurship activities, undertaken by NPK, shall directly impact the livelihoods of the farmers of the semi-arid tropics. These activities shall enhance the income level of poor farmers of the semi-arid tropics through increased demand and higher market price of their farm produce. Some of the value-added products, which have been developed by NPK, from the dryland crops are Healthy low-fat snacks made from Sorghum and Pearl millet, Refreshing flavoured beverage formulated from sweet-sorghum syrup, sweet sorghum based waffle syrup, sweet sorghum toffee, energy bar, multi-grain cookies, tamarind-sweet sorghum sauce etc. (Fig 7).

		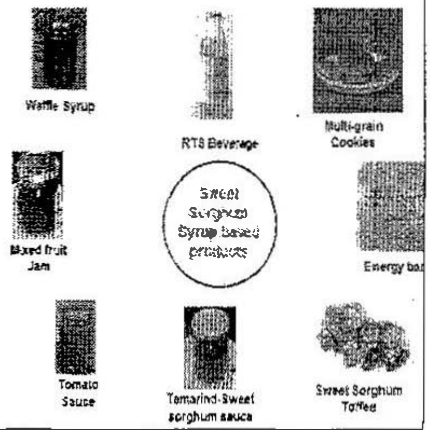
(a) Healthy low-fat snacks made from Sorghum and Pearl millet	(b) Refreshing flavored beverage formulated from sweet-sorghum syrup	(c) Other value added products based on sweet sorghum syrup

Figure 7.Innovative value-added food products developed from dryland crops by the NutriPlus Knowledge (NPK) program of the ICRISAT's Agribusiness and Innovation Platform (AIP)

Recommendations:

- Resilient crops and cropping systems need to be identified for different agro-ecological regions in the dry land areas.
- Cultivars tolerant to high temperature, water stress and other biotic and abiotic stresses should be developed.
- Retarget and redeploy the existing long duration cultivars to mitigate the climate change induced decrease in length of growing period.
- Adopt integrated watershed management based approach for soil and water conservation, improve productivity, enhance water supply, livestock management and provide income generating activities through product value addition and other off-farm activities.
- Efficient use of harvested rain water to provide life saving irrigations.
- Follow integrated plant nutrient management systems, balanced plant nutrition, conservation agriculture practices, IPM/IDM for proper and healthy plant growth and development.

Conclusion:

As the dry lands will become increasingly important to ensure the nations' food security 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. This is also important for the livelihood security of millions of the poor people who live in arid and semi-arid regions. ICRISAT believes that in the medium term (2010-2050), it is well placed to help the dryland farmers to cope up the climate change effects by retargeting and redeploying its current long duration varieties and soil, water and crop management techniques developed at the ICRISAT over the years. Integrated watershed management holds great promise to minimise the climate change effects on dryland agriculture through soil and water conservation, productivity enhancement, promotion of agroforestry and income generation activities through value addition and other off-farm activities.

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