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Integrating Crop Improvement with Resource Management to Alleviate the Effects of Desertification under Climate Change Scenarios

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Desertification is one of the major challenges human society facing today and it is exacerbated by climate change, and threatens sustenance of human life on the planet. Desertification refers to the process of fertile land transforming into desert, typically as a result of deforestation, drought or improper/inappropriate agriculture. Desertification is a serious problem for the drylands owing to climate change or anthropological reasons affecting the agricultural production and sustainability of ecologies (Geist, 2005). Drylands occupy approximately 40% of Earth's land area and are home to more than 2 billion people. It has been estimated that nearly 10–20% of drylands are already degraded, the total area affected by desertification being between 6 and 12 million square kilometers, that about 1–6% of the inhabitants of drylands live in desertified areas, and that a billion people are under threat from further desertification (Johnson *et al.*, 2006; World Bank, 2009). Therefore, it is important to understand the process of desertification, factors contributing to it and interventions needed to combat desertification for enhancing the agricultural productivity and sustaining the environment. Various public and private sector institutions, international and national centers, civil society organizations are working on formulating and implementing programs to combat desertification.

Globally, desertification, along with climate change and the loss of biodiversity were identified as the greatest challenges to sustainable development during the 1992 Rio Earth Summit (http://www.unccd.int/en/about-the-convention/Pages/About-the-Convention.aspx verified on 6th July 2012). Convention for Combating Desertification was established under the United Nations umbrella (UNCCD) in 1994, which is a legally binding international agreement linking environment and development to sustainable land management with a membership of 194 countries (http://www.unccd.int/Lists/SiteDocumentLibrary/Publications/Forgotten%20Billion.pdf verified on 6th July 2012). The Convention addresses specifically the arid, semi-arid and dry sub-humid areas, known as the drylands, where some of the most vulnerable ecosystems and peoples can be found, with a major goal: *"to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability"* (http://www.unccd.int/en/about-the-convention/Pages/About-the-Convention.aspx verified on 6th July 2012).

The UNCCD's 194 parties work together to improve the living conditions of people in drylands, to maintain and restore land and soil productivity, and to mitigate the effects of drought. It follows a bottom-up approach, encouraging the participation of local people in combating desertification and land degradation. As the dynamics of land, climate and biodiversity are intimately connected, the UNCCD collaborates closely with the other two Rio Conventions; the Convention on Biological Diversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC), to meet these complex challenges with an integrated approach and the best possible use of natural resources. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), mandated to reduce poverty, hunger, malnutrition and

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environmental degradation in the dryland tropics is working towards this goal through improving the crops, production systems and markets by following partnership based international agricultural research approach.

Sorghum, pearl millet, pigeonpea, chickpea and groundnut are predominant crops grown under dryland semi-arid tropical areas. ICRISAT serves as a world center for the improvement of sorghum, pearl millet, pigeonpea, chickpea and groundnut; and also conducts research on improved farming systems to optimize the use of human and natural resources in the low rainfall, seasonally dry semi-arid tropics (SAT) regions. ICRIAT gene bank conserves >120,000 accessions of genetic resources of the five mandate crops (sorghum, pearl millet, chickpea, groundnut and pigeonpea), and six small millets. The SAT covers parts of 55 developing countries inhabited by about 1.4 billion people, of which 560 million (40%) are poor, and 70% of these live in rural areas. SAT ecosystem is characterized by extreme rainfall variability, recurrent and unpredictable droughts, high temperatures, less fertile soils and intense pest and disease pressure. Some of the SAT marginal lands are on the brink of desertification.

Climate change is posing bigger challenges in terms of higher temperatures, increased rainfall variability and elevated CO_2 levels in the atmosphere. ICRISAT aims at developing improved varieties of its mandate crops – sorghum, pearl millet, chickpea, pigeonpea and groundnut – to cope better with a warmer world, through genetic improvement for heat and drought tolerance and resistance to potential new and more severe pest and disease attacks. Such varieties are expected to enable the farmers to better cope up with the climate change effects and desertification through use of adapted cultivars and best-bet practices for soil, water and nutrient management in different agro climatic conditions.

Sorghum and pearl millet are important staple food grain crops of SAT Asia. Over the last three decades, the area planted to both these crops has fallen by nearly one-third. The area under rainy-season sorghum fell by nearly one-half, while that under postrainy-season (rabi) sorghum remains essentially the same. But there were substantial productivity gains (especially in pearl millet) so that the production of these grains reduced less sharply or remained stable, primarily due to deployment of hybrid cultivars. The area under other important SAT crops such as pigeonpea, chickpea and groundnut has remained relatively constant during this period. Chickpea has entered in to non-traditional areas and recorded impressive yield gains in the last two decades. For example, in the state of Andhra Pradesh the area has gone up by 3.8 fold with the introduction of short-duration varieties (Gaur *et al*., 2012). The new spring season groundnut cultivation in Uttar Pradesh, India, has revived the area, reaching to 200,000 ha in 2010, under this crop in the last decade.

Hybrids in sorghum, pearl millet and pigeonpea offer about 30-40% grain yield advantage over varieties (Reddy *et al*., 2004). Drought tolerant groundnut varieties recorded an on-farm pod yield advantage of 23% and generated 36% higher net profit returns compared to local popular variety, TMV 2 (Birthal *et al*., 2011). ICRISAT's major efforts in crop improvement include pre-breeding, genetic diversification and enhancement, and sharing advanced breeding lines and improved hybrid parents with both the public and private sector partners. Advances in crop improvement of ICRISAT mandate crops, and future technology needs to meet the challenges of climate change and desertification are briefly discussed in this paper.

Advances in Improvement of Semi-arid Crops

Sorghum

Sorghum [*Sorghum bicolor* (L.) Moench], grown on 40 m ha is the fifth most important cereal crop globally, and is a major staple crop grown in the semi-arid regions of the world. It is predominantly a self pollinated crop, but use of cytoplasmic-nuclear male sterility systems has facilitated the development of hybrids.

Hybrid parents' research in sorghum in earlier years had greater emphasis on rainy season sorghum compared to postrainy *(rabi)* season, because of large acreage in rainy season at the global level, higher yield potential, larger germplasm diversity and less stringent grain and fodder quality requirements. Most of the commercial hybrids produced so far are based on a single cytoplasm, designated as *milo* or

A_1 (Reddy and Stenhouse, 1994; Moran and Rooney, 2003). High priority is now given to diversification, to broaden the genetic base of cytoplasmic male sterile (CMS) lines, which led to the development of male-sterile lines with non-milo CMS systems such as A_2, A_3, A_4 (VZM), A_4 (Maldandi) and A_4 (Guntur). Efforts are underway on race-specific and non-*milo* CMS systems for diversification of A- lines (Ashok Kumar *et al.,* 2011).

Considering the importance of postrainy season (rabi) adaptation, the emphasis is shifted towards diversification of hybrid parents for farmer-preferred grain quality traits such as white, large and lustrous grains, and also tolerance to terminal moisture stress. Diversification of seed parents for resistance to biotic stresses was prioritized to address two major stresses, namely shoot fly (for both rainy and postrainy season sorghums), and grain mold (for rainy season). Development of A-/B-pairs for multicut trait, sweet stalk trait, salinity tolerance and high grain micronutrients (Fe and Zn) contents are some of the new research programs initiated in the recent years (Ashok Kumar *et al*., 2011; Reddy *et al.,* 2011).

Pearl millet

Pearl millet [*Pennisetum glaucum (L.)* R. Br.] is annually grown on more than 29 m ha in the arid and semi-arid tropical regions of Asia, Africa and Latin America. India is the largest producer of pearl millet, both in terms of area (9.3 m ha) and production (8.3 m ton). It is mostly grown in hot-dry parts of India in regions receiving low annual rainfall ranging from 200-800 mm. As compared to the early 1980s, the pearl millet area in India declined by 19%, but production increased by 28%, owing to a 64% increase in productivity (from about 450 kg ha^{-1} (during 1975-77) to 870 kg ha^{-1} (during 2005-07).

Pearl millet is a highly cross-pollinated crop with protogynous flowering and wind-borne pollination. Because of high degree of out crossing, development of open pollinated varieties (OPVs) and hybrids are viable cultivar options for exploiting heterosis in pearl millet.

Pearl millet hybrid development programs globally have been based on A_1 CMS system; hence more emphasis is on diversification of the CMS systems at ICRISAT. Among the various alternative CMS systems evaluated (A_2 and A_3 from India, A_4 from USA, A_v from France, and A_{egp} and A_5 identified at ICRISAT), A_4 and A_5 CMS systems to be distinctly different from others and useful in hybrid breeding programs (Rai *et al*., 2006).

Drought is the most serious abiotic production constraint in pearl millet. Large genetic variability has been detected for drought tolerance in pearl millet and effective screening protocols have been identified, permitting further improvement of this trait. Breeding for resistance to downy mildew resistance is a major breeding goal. Other breeding objectives include: dual-purpose and fodder pearl millet, enhanced zinc and iron content in grain (biofortification), and salinity tolerance.

Pigeonpea

Pigeonpea [*Cajanus cajan* (L,) Millsp.] is grown in Asia, Eastern and Southern Africa, Latin America and the Caribbean countries on about 4.9 m ha area with an annual production of 3.65 m t and productivity of 790 kg ha^{-1}. In Asia, India (3.58 m ha), Myanmar (560,000 ha), China (150,000 ha), and Nepal (20,703 ha) are major pigeonpea growing countries. Between 1976 and 2006, pigeonpea recorded 56% increase in area (2.76 to 4.32 m ha) and 54% increase in production (2.14 to 3.29 m t). However, productivity has remained stagnant.

Pigeonpea is predominantly self-pollinated, but insect-aided pollination leads to out crossing (≃20%). Since it is invariably grown in marginal environments with minimum inputs, the stability of performance has received due attention. Emphasis is to incorporate resistance/ tolerance to fusarium wilt, sterility mosaic disease, and insect-pests (particularly pod borer). ICRISAT research focuses on medium maturity (160-180 days) group hybrids and pure line varieties for central and peninsular India and extra-early (<120 days) cultivars for north-west India and other niches that have short crop-windows.

Using genetic male sterility (GMS) system, hybrids were developed and released in India (Saxena *et al*., 1992). In spite of high yields, these hybrids were not extensively adopted due to difficulties in seed production and high cost of seed. Cytoplasmic-genetic male sterility (CGMS) system was developed at ICRISAT by combining the cytoplasm of wild relatives with the nuclear genome of cultivated pigeonpea. Several extra-short, short- and medium-duration hybrids with A_4 and A_5 CMS system have been evaluated in multilocation trials. Among medium maturing hybrids, (ICPH 2671) exhibited 47-64% heterosis over the best control cultivar. Currently ICRISAT is working with public and private sector partners to produce hybrid seeds for adoption by small holder farmers.

Groundnut

Groundnut (*Arachis hypogaea* L.), 6th important oilseed crop, is currently grown on over 22 m ha area worldwide with a total production of 35 m t. Developing countries account for over 97.6% of world groundnut area and about 95.5% of total production with average yield of 1522 kg ha^{-1}. Production is concentrated in Asia and Africa, where the crop is grown mostly by smallholder farmers under rain-fed conditions with limited inputs.

Improved varieties with high yield potential of over 9 t ha^{-1} have been developed. However, the average yield of groundnut is 1450 kg ha^{-1}. Abiotic, particularly drought, and biotic stresses chiefly, rust, leaf spot and aflatoxin, are the main reasons for this large variation in yield among countries. Thus, stress tolerance breeding is the core research activity in most breeding programs. At ICRISAT groundnut breeding program focuses mainly on tolerance to drought, early maturity (to escape terminal drought) with good yield potential, and resistance to major diseases (late leaf spot, rust and aflatoxin). Varieties with better performance under drought conditions have been developed and released (e.g.: ICGS 1, 5, 11, 37, 76, 44). Recently a new drought tolerant groundnut variety, ICGV 91114, is gaining popularity in Andhra Pradesh, Orissa, Karnataka states in India. Excellent sources of rust resistance are available and many improved rust resistant varieties have been released. Due to limited tolerance in cultivated germplasm wild relatives are being used as sources of resistance to leaf spot disease; improved released varieties include ICGV 86590 and ICGV-SM 86715.

In developing countries including India adoption of improved varieties by farmers has been poor mainly because lack of knowledge and limited availability of seeds of improved varieties. In order to enhance the awareness and to increase adoption of improved cultivars and breeding lines, farmers' participatory varietal selection and seed production, particularly in the informal seed sector, are being implemented in various states of India.

In India, about 80% of its 7 million tonnes annual groundnut produced is crushed to extract oil used for edible and industrial uses. The oil content in the currently cultivated groundnut varieties is about 48%. A market survey report has indicated a price premium for high oil content. Recently, ICRISAT has been successful in breeding newer varieties possessing as much as 55% oil with high yield potential resulting in high oil yield per unit area. These varieties have the potential to boost groundnut oil production.

Chickpea

Chickpea (*Cicer arietinum* L.) is the third most important food legume globally after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.). India is the largest chickpea producing country with a share of 64% in the global chickpea production. During the triennium 2007-2009, the global chickpea area was about 11.5 m ha with a production of 8.8 m tons and average yield of nearly 850 kg ha^{-1}.

Chickpea is generally grown without irrigation, in the postrainy season, and terminal drought (moisture stress that occurs at the reproductive stage of the crop growth) is a major constraint to production. At ICRISAT we follow three breeding strategies for drought tolerance: (i) selection for grain yield under moisture stress conditions, (ii) breeding for components of drought tolerance, and (iii) breeding for short-duration cultivars that can escape terminal drought. The first strategy involves selection for yield and its components under given water limiting test plots or under drought-stressed environments. Targeted approaches for improving components of drought tolerance are also being implemented.

Root traits, such as rooting depth and root biomass, play an important role in drought tolerance by improving water availability to the plants through more efficient extraction of the available soil moisture. Efforts have been made to identify molecular markers closely linked with major QTLs controlling root traits to facilitate MAS for root traits and their subsequent introgression into adapted cultivars (Chandra *et al*., 2004 and Gaur *et al*., 2008).

Other major traits include resistance to fusarium wilt, ascochyta blight, botrytis gray mold and *Helicoverpa* pod borer. Emphasis is also placed on market preferred traits such as large seed size, in both *desi* and *kabuli* types. Since the level of resistance to *Helicoverpa* in cultivated chickpea is low to moderate, attempts are being made to enhance the level of resistance by combining different mechanisms of resistance available in the wild and cultivated species. Transgenics using *Bt* insecticidal protein genes (*cry1Ac* and *cry1Ab*) and soybean trypsin inhibitor gene (Sharma *et al*., 2004) are being attempted.

Impact of Climate Change on Production and Productivity of Rainfed Crops

Climate change further complicates the complex issue globally in dryland farming. There is overwhelming evidence of climate change, but uncertainty prevails over the exact nature and consequences of climate change especially at the local level, making it difficult to plan and develop appropriate adaptation strategies, programs, and technologies. Simulations using different climate models provide various scenarios with high levels of confidence, but these predictions become less clear as to the magnitude and timing of the changes at sub-regional, national and local levels. Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales (IPCC, 2007). However, it is widely recognized that the increased heat stress, shift in monsoons, and drier soils pose much greater threat to the tropics than the temperate regions (Rosenzweig and Liverman, 1992)· With most developing countries located in the tropics and sub-tropics and most of them being heavily dependent on rainfed agriculture for food and income, the relatively poor countries with limited resources face the costly and formidable task of adapting to climate change. Despite the many assumptions and uncertainties associated with the crop and climate models, the analysis has indicated that South Asia and Southern Africa are the two regions that are particularly sensitive to the impacts of climate change, and without sufficient adaptation measures, are likely to suffer from negative impacts of climate change (Lobell *et al*., 2008). Climate change has the potential to negatively impact developing countries' prospects for sustainable development. As the rural poor across the developing world feel the pressure of climate change, high food prices and environmental and energy crises, new knowledge, technologies and policy solutions are essential.

Climate Change: The Hypothesis of Hope for the Semi-Arid Tropics

Using a range of weather data-driven tools, ICRISAT's scientists have initiated research to test the hypothesis that in the medium term (2010-2050), ICRISAT and its partners are well placed to help farmers cope up with the challenges, and exploit the opportunities that are posed by climate change. Climate change will modify the length of the growing period across the regions of interest, but this can in large part be mitigated by the re-targeting and re-deployment of existing germplasm. Predicted temperature increases, through their effect on increasing rate of crop growth will have greater negative impact on crop production than relatively small (+/- 10%) changes in rainfall (Cooper *et al*., 2009).

The schematic framework for 'hypothesis of hope' developed is depicted in Figure 1. It identifies 3 yield gaps that need to be addressed in seeking solutions to both, current and future climate-induced production risk.

The current yield gap

Column 1 represents the yields realized by the farmers under their current and relatively low input management. Column 5 represents the yields that farmers could get through the adoption of simple and affordable recommendations for improved variety and crop, soil and water management practices. This is the yield gap that we are currently addressing.

Yield gap 1 under climate change

Column 2 represents the marginally decreased yields that farmers would get under changed climate scenario, if they were to continue using the same low input system. We have shown earlier that under such low input systems, other factors continue to provide the overriding constraint. Column 3 represents the yields that farmers could get, even under climate change, if they adopted improved crop

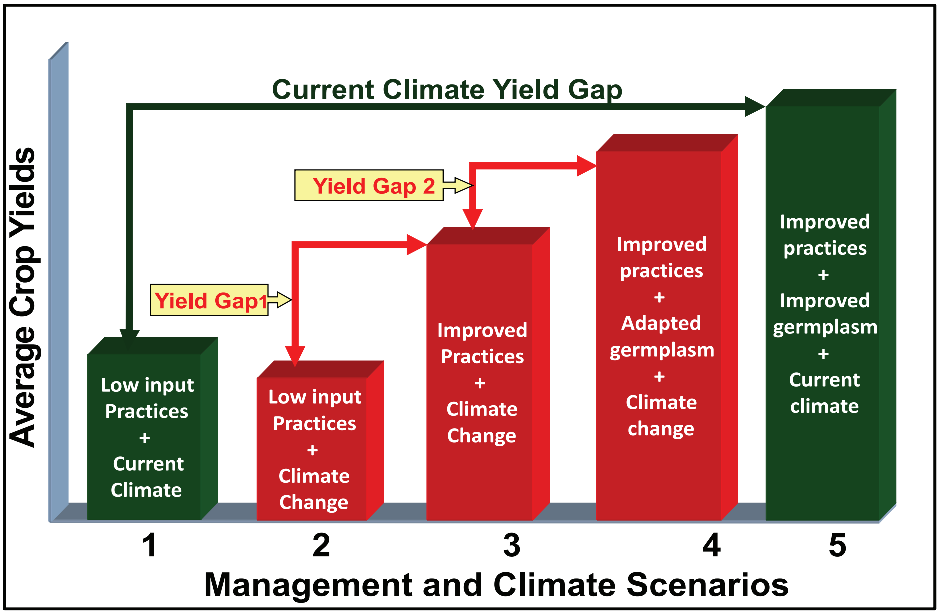

Fig. 1. 'Hypothesis of Hope' Schematic Framework

management practice recommendations. This is the yield gap that we are and will continue to address through our work to develop, scale-up and scale-out enhanced crop, soil and water management options for farmers in the semi-arid tropics.

Yield gap 2 under climate change

Column 4 represents the yields that farmers could get under climate change if they were to adopt current improved practice recommendations together with germplasm better adapted to a warmer world. Within the scope of the *ex ante* analyses that we have done so far, we consider better adaptation to solely constitute varieties whose maturity length is better suited towards growing in a warmer world. We recognize that other factors such as 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 we need to address 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 (Cooper *et al*., 2009).

Policy makers should take notice of the fact that better formulated and targeted policies that facilitate and support the adoption of agricultural innovation today assume even greater urgency. Not only will they improve the welfare of rural population today but will do a great deal to mitigate the impacts of future climate change.

Crop improvement Strategies for Climate Change Adaptation

While continuing its efforts to combat the current challenges in rainfed farming ICRISAT identified medium-term (10-40 years) priority strategies that will result in crop varieties and cropping systems that are adapted to a changed environment in future. As discussed in earlier sections, a blend of crop improvement and natural resource management technologies help in overcoming the climate change effects in agricultural production. Better weather forecasting methods and water management techniques, best-bet interventions, natural resource management and knowledge sharing in the short run and use of adapted crop cultivars and appropriate crop and natural resource management methods and better policies hold the key in the long run (Singh *et al*., 2011). Some of the products and technologies that help rainfed farming to meet the current and future changes are given below.

Stay-green trait in sorghum and pearl millet

Sorghum and pearl millet are staple cereal grain and fodder crops grown by subsistence farmers in sub-Saharan Africa and the Indian subcontinent and presumably they are the most heat- and drought-hardy crops. Researchers at ICRISAT and elsewhere are using conventional breeding and marker assisted selection (MAS) to identify and isolate genes and improve sorghum for "stay-green" trait that allows the plant to mature normally under moisture and heat stress (Haussmann *et al*., 2002). Stay-green genes delay the senescence of leaves, help the normal grain filling, and reduce the incidence of lodging (Reddy *et al*., 2007). Stay-green lines in elite agronomic backgrounds have also been identified in pearl millet which has maintained this trait under diverse climatic conditions.

Exploiting the photoperiod sensitivity

Sorghum and pearl millet researchers in Africa and Asia are focusing attention on photoperiod-sensitive breeding lines that give farmers an added tool to adapt to rainfall variability. These plants have been "programmed" to mature at the time of year when conditions are most likely to be favorable for grain development, regardless of when they are planted (Clerget *et al*., 2007). Photoperiod-sensitive sorghum and pearl millet will adjust their flowering and grain filling at a roughly constant calendar date, which tends to be the period when the rains have stopped but there is still enough soil water to complete grain development (House, 1985).

Enhance forage potential of dry land crops

Shortage of fodder is the main constraint for livestock production in rainfed areas which is inhabited by 60% of the cattle population, making it mandatory to increase the production of crops with high forage potential. Owing to their high biomass production ability, high level of water use efficiency, tolerance to heat and drought, with lesser incidence of diseases and insect pests, pearl millet and sorghum can serve as excellent forage crops. To exploit the forage potential of sorghum and pearl millet, concerted efforts are required to breed for easily identifiable and highly heritable traits like high tillering, low stem thickness and more leafy plants with more glabrous leaves. Attempts in the past for developing pearl millet hybrids using high forage yielding OPVs on some of the A-lines (developed primarily for grain production), did not show the desired forage yield advantage over OPVs, indicating the need to develop A-lines specifically for forage purposes. However, sweet sorghums and high biomass sorghum lines have high forage quality indicating their utility in meeting the forage demands (Ashok Kumar *et al*., 2010).

Targeting hybrid technology in marginal environments

Hybrid technology has led to significant yield enhancement in better-endowed environments of rainfed farming ecologies, but large parts of north-western India having arid type marginal environments are yet to harness such advantage. There is a need to breed more productive lines for such environments, especially for pearl millet. Experiments have shown that hybrids developed from high yielding parental lines bred in favorable environments cannot deliver hybrids for these marginal environments. Thus, to penetrate hybrid technology in pearl millet in this zone, the right approach should be to develop hybrid parental lines involving locally adapted germplasm for improvement in grain and stover yield potential combined with DM resistance and drought tolerance. ICRISAT and its partners are working in this direction to develop hybrids to suit marginal environments.

Early maturing genotypes to escape terminal drought

Terminal drought is a major production constraint in rainfed agriculture. Development of early maturing cultivars (to match with the period of soil moisture availability) without compromising the productivity is essential for enhancing production. ICRISAT-developed early maturing chickpea cultivars have helped in overcoming the terminal drought and expanded the chickpea cultivation to non-traditional areas with shorter and warmer growing season.

Studies on impact of temperature increase on rates of crop growth and yield (Cooper *et al*., 2009) indicate that there will be reduction in 'time to maturity' of cultivars. This means in a warmer world, a currently defined 'medium duration' type will become a 'short duration type'. Considering this, the crop improvement programs in future should focus on medium to late maturing genotypes with heat tolerance and pest and disease resistance to deal with the yield reduction resulting from temperature increase.

To cite a few instances of our successes so far, we have ICCV 2, the world's shortestduration *kabuli* chickpea variety that matures in 85-90 days escaping terminal drought; groundnut variety ICGV 91114 that is popular in Ananthapur district, Andhra Pradesh for its ability to withstand long dry spells (Birthal *et al.*, 2011); pigeonpea hybrid ICPH 2671 which is highly resistant to two major diseases – fusarium wilt and sterility mosaic; and pearl millet hybrid HHB67-Improved which matures in 62-65 days, making it the earliest maturing commercial pearl millet hybrid in the world.

Heat tolerant genotypes

The CGIAR's Climate Change for Agriculture and Food Security (CCAFS) research has shown that high temperature stress (above 30°C) will be widespread in East and Southern Africa, India, South East Asia and Northern Latin America, which are important groundnut growing areas. Pearl millet and sorghum are better adapted to high temperature conditions. Sorghum flowers and sets seed under high temperatures (up to 43°C) provided soil moisture is available (House, 1985). Selecting the breeding lines that do not compromise on yield and quality at elevated temperatures has been the most common method to develop varieties to the hot target production environments. Sensitive stages for heat were identified in pearl millet and groundnut.

Specific breeding action plans for climate change adaptation

Here is a brief outline of specific breeding plans for each of ICRISAT mandate crops in view of climate change:

a) Sorghum

i. Selection for improving OPVs and hybrid parents for germination and growth under high temperature and water stresses.
ii. Breeding for tolerance to soil salinity and acidity.
iii. Development of heterotic gene pools for tolerance to high temperatures and moisture stress.
iv. Identification and transfer of QTLs for stover quality for development of improved hybrid parental lines.

b) Pearl millet

i. Development of early maturing parental lines with higher grain and stover yield and tolerance to drought.
ii. Improvement of locally adapted germplasm for higher grain and stover yield coupled with DM resistance
iii. Strengthening of germplasm base with high forage potential
iv. Identification and transfer of QTLs for drought tolerance, DM resistance and stover quality for development of improved hybrid parental lines.

c) Groundnut

i. Understanding physiological mechanism underlying heat tolerance, developing screening techniques, and identifying heat tolerant genotypes.
ii. Short-duration cultivars that suit short-growing seasons, necessitated by end-of-season droughts, cooler temperatures and early frosts.
iii. Identification and transfer of QTLs for drought tolerance and development of varieties better adapted to drought.

d) Pigeonpea

i. Developing cost-effective screening techniques for heat, drought, salinity and water-logging tolerance and developing/identifying genotypes for these conditions
ii. Identification of germplasm for maintaining transpiration efficiency and better partitioning under increased temperature and drought.

e) Chickpea

i. Development of heat tolerant varieties.
ii. Selection for early maturity (for drought escape).
iii. Identification of germplasm for high transpiration efficiency and partitioning under increased temperature stress.

Conclusions

Farming in rainfed environments has been a daunting task, and it is going to be much more challenging with the predicted climate change and its associated effects in terms land degradation, water shortage, loss of biodiversity. We need to make special efforts in agriculture R & D and policy advocacy to prepare the rainfed farmers to cope with these challenges. A combination of adapted cultivars, improved crop and natural resource management practices, better weather forecasting, improved access to inputs, institutional credit and markets, provision of crop insurance, policy support and capacity building of stakeholders contribute to enhanced productivity and incomes in rainfed agriculture in future. ICRISAT with its new strategic plan for 2020 envisioning inclusive market oriented development based on systems perspective in place, along with its partners is poised to ensure the food and nutritional security and increased incomes to small holder farmers in Africa and Asia.

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