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Capacity Building for Climate Smart Agriculture

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3

Impact of Climate Change on Agriculture and Food Security

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3.1 Introduction

Evidences over the past few decades show that significant changes in climate are taking place all over the world as a result of enhanced human activities in deforestation, emission of various greenhouse gases, and indiscriminate use of fossil fuels. Global atmospheric concentration of CO_2 has increased from pre-industrial level of 280 parts per million (ppm) to 400 ppm in 2014. Global projections indicate higher temperature of 1.5 to 4.5°C by the year 2050, as a result of enhanced greenhouse gases. Climate change predictions for India indicate that warming is likely to be above the global mean and fewer very cold days are very likely. Frequency of intense rainfall events and winds associated with tropical cyclones are likely to increase.

Various studies show that climate change in India is real and it is one of the major challenges faced by Indian Agriculture, more so in the semi-arid tropics (SAT) of the country. India ranks first among the countries that practice rainfed agriculture in terms of both extent and value of production. Rainfed agriculture is practiced under a wide variety of soil types, agro-climatic and rainfall conditions. Rainfed agriculture supports nearly 40% of India's estimated population of 1.21 billion in 2011 (Sharma 2011). The rainfed agro-ecologies cover about 60 per cent of the net sown area of 141 million ha and are widely distributed in the country (DOAC, 2011). Even after achieving the full irrigation potential, nearly 50% of the net cultivated area may remain dependent on rainfall. Changes in climate would affect agriculture directly through abiotic stresses and indirectly through biotic stresses. Climate change is seen as changes in temperature, increased variability in rainfall, enhanced carbon dioxide concentrations. Climate change is likely to make changes in the length of the rainfed crop-growing period. Rainfed agriculture in India plays a crucial role in ensuring food security for the larger and poorer segment of the population but often it coincides with a high incidence of poverty and malnutrition. Reduction in yields due to climate change is likely to be more prominent in rainfed agriculture and under limited water supply situations.

Crop yields in dryland areas of the country are quite low (1-1.5 t ha^{-1}) which are lower by two to five folds of the yields from researchers' managed plots (Bhatia et al., 2006). Current rainwater use efficiency in dryland agriculture varies between 35-45% and vast potential of rainfed agriculture could be unlocked by using available scientific technologies including improved cultivars.

3.2 Climate Change and Variability

Due to anthropogenic activities, a steady increase in atmospheric turbidity is observed in India. Indian annual mean (average of maximum and minimum), maximum and minimum temperatures showed significant warming trends of 0.51, 0.72 and 0.27°C 100 yr^{-1}, respectively, during the period 1901–2007 (Kothawale et al. 2010). However, accelerated warming was observed in the period 1971–2007, mainly due to intense warming in the recent decade 1998–2007.

Mean annual temperature of India in 2010 was +0.93°C above the 1961-1990 average and the India Meteorological Department (IMD) declared that 2010 was the warmest year on record since 1901. Mean temperature in the pre-monsoon season (March-May) was 1.8°C above normal during the year 2010.

At the country scale, no long-term trend in the southwest monsoon rainfall was observed, although an increasing trend in intense rainfall events was reported. Goswami et al. (2006) analysed gridded rainfall data for the period 1951-2000 and found significant rising trends in the frequency and the magnitude of extreme rain events, and a significant decreasing trend in the frequency of moderate events over central India during the monsoon seasons. The seasonal mean rainfall does not show a significant trend, because the contribution from increasing heavy events is offset by decreasing moderate events. They concluded that a substantial increase in hazards related to heavy rain is expected over central India in the future. Increased frequency and intensity of extreme weather events in the past 15 years were reported (Samra et al. 2003 and 2006).

A study carried out by ICRISAT under the National Initiative on Climate Resilient Agriculture (NICRA) project described a net reduction in the dry sub-humid area (10.7 m ha) in the country, of which about 5.1 Million ha (47%) shifted towards the drier side and about 5.6 Million ha (53%) became wetter, comparing the periods 1971-1990 and 1991-2004 (Kesava Rao et al., 2013). Results for Madhya Pradesh have shown the largest increase in semi-arid area (about 3.82 Million ha) followed by Bihar (2.66 Million ha) and Uttar Pradesh (1.57 Million ha). Relatively little changes occurred in AP; semi-arid areas decreased by 0.24 Million ha, which were shifted to both towards drier side (0.13 Million Ha under arid type) and wetter side (0.11 Million Ha under dry sub-humid type). Results indicated that dryness and wetness are increasing in different parts of the country in the place of moderate climates existing earlier in these regions.

Weather-generating models are widely used for studying the climate change over longer periods. Reddy et al., (2014), have evaluated the LARS-WG model for southern Telangana region (Hayathnagar, Yacharam and Rajendranagar). A 30-year base weather data (1980–2010) was used to generate the long-term weather series from 2011 to 2060. The model predicted the maximum increase in average annual rainfall of 5.2% in 2030 and 9.5% in 2060 for Yacharam compared to Hayathnagar and Rajendranagar over the normal annual rainfall of the base period (1980–2010). In case of air temperature, the model predicted increase in maximum temperature in the range 1–1.5% and 2.5% for 2030 and 2060 respectively, for these locations whereas minimum temperature decreased in the range 3.7-10.2% and 6.3- 11.7% respectively, for 2030 and 2060.

In the northern districts of Karnataka, annual rainfall variability analysis based on hundred years' data (1901-2000) indicated a periodicity of 13-17 years' cycle. A general decrease of rainfall in September and large increase in October over northern Karnataka during the 20th century was seen. Corresponding decrease in maximum temperature during October was noticed. Increased temperatures in November and December are observed, indicating availability of higher thermal energy for better vegetative growth during November while greater thermal stress during flowering period in December for post-rainy sorghum crop (Venkatesh *et al.*, 2008).

Using a high spatial resolution (0.25° × 0.25°, latitude × longitude) climate data for the period 1901-2013, pixel-wise water balances and climate indices were computed based on the revised water budgeting approach of Thronthwaite and Mather (1955). Climates for each year were classified based on the annual moisture index as per classification of Thornthwaite and Mather (1955).

The period 1901-1990 is considered as the base period or period 1 and 1991-2013 is considered as period 2. Average climates classified into six types for both the periods 1 and 2. Considerable changes in climates are observed between the two periods, 1901-90 and 1991-2013 (Table 3.1). Arid area has decreased by about 0.574 m ha and much of it has shifted to the Semi-Arid climates. Interesting feature is that there is an eastward shift in the arid areas in the districts of Belgaum, Bagalkot, Koppal and Raichur. Areas under Semi-Arid and Perhumid climates have increased by about 0.334 and 0.316 m ha. Dry Sub-humid areas increased by about 0.12 m ha and Humid areas are reduced by about 0.161 m ha. Very little decrease of 0.035 m ha was observed in the Moist Sub-humid type of climate. Overall it is seen that Per humid, Dry Sub-humid, Moist Sub-humid and Semi-Arid areas have increased by about 27, 13, 8 and 3 per cent respectively, compared to their normal 90-year climate as seen in the period 1 (1901-1990). Arid and Humid climate areas have decreased by about 15 and 4 per cent respectively.

Table 3.1 Area changes under different climates in Karnataka

Area in million ha

Period	Arid	Semi-Arid	Dry Sub-humid	Moist Sub-humid	Humid	Per Humid	Total
1901-1990	3.775	11.688	0.929	0.452	1.149	1.186	19.179
1991-2013	3.201	12.022	1.049	0.417	0.988	1.502	19.179
Difference	-0.574	0.334	0.12	-0.035	-0.161	0.316	0
% Change	-15	3	13	8	-4	27	0

3.3 Climate Change Impacts

Due to global warming, length of the growing period (LGP) is likely to increase, however due to increase in day and night temperatures, physiological development is accelerated resulting in hastened maturation and reduced yields. Increased night time respiration may also reduce potential yields. With global climate change, rainfall variability is expected to further increase. When decrease in rainfall coupled with higher atmospheric requirements due to elevated temperatures, the LGP is likely to shorten. At Nemmikal watershed in the Nalgonda district of Telangana, the LGP has decreased by about 15 days since 1978 and the climate has shifted to more aridity from semi-arid (Wani et al., 2012). Shift in the length of growing period, if not understood by the farmers, generally results in more crop failures due to late season drought (Fig. 3.1). Present popular varieties of maize and pigeonpea are likely to produce lower yields more often in future.

In Karnataka, Eastern Dry agroclimatic zone consists of Bangalore and Kolar districts and parts of Tumkur district, which is also known as the Tank-fed region. Rajegowda *et al.*, 2000 have shown that there is a predominant shift in the initiation and termination of rainfall to supply adequate moisture for crop growing period. This shift has been observed after 1990 and their mean monthly values also have changed. Before 1990, the annual rainfall ranged from 619 to 1119 mm with a mean of 869 mm.

After 1990, the annual rainfall ranged between 611 and 1311 mm with a mean of 1011 mm. During the first period, on an average, the peaks were observed during May, July and September while during the second period, the peaks were observed during May, August and October. There is a perceptible shift in rainfall pattern from July to August and also from September to October in this agroclimatic zone.

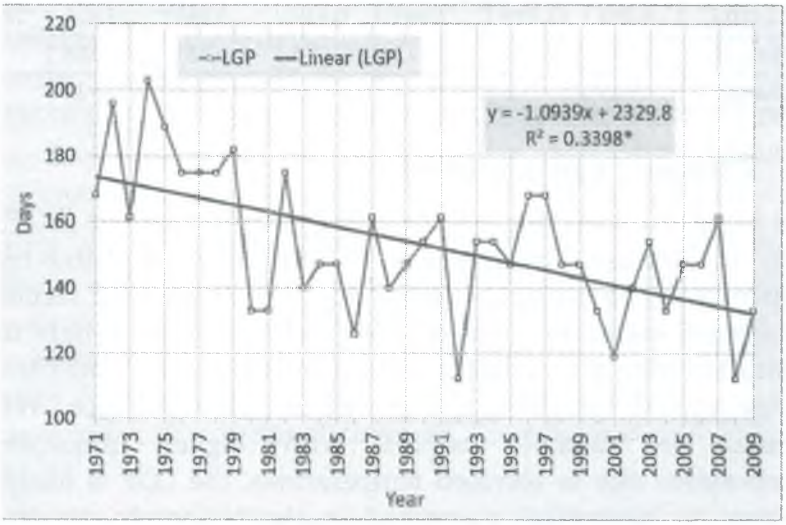

Fig. 3.1 Shift in Length of Growing Period at Nemmikal, Nalgonda district

Crops sown during July rains would reach the grand-growth period viz., flowering to grain formation stage (long duration crops of about 115 days) during September which was receiving the highest rainfall till 1990, so that there was no moisture stress during the grand growth period. After 1990, as a result of reduction in July and September rains, the crops cannot be sown during July, though the land preparation could be done using June rains. Even with scanty rains, if the sowing is done during July, the crop would suffer from moisture stress due to the reduction in rainfall during September and also the crop grown would be caught in October rains causing considerable loss in the grain yield. This analysis revealed that in the Eastern Dry agroclimatic zone, sowing of crops (long duration variety crops of about 115 days) could be done during August preparing the land using June and July rains. In the years of early onset of southwest monsoon, sowing can be recommended during last week of July also. Crops sown during August would reach the grand growth period during October. As October receives higher rainfall the crop in its grand-growth period would not suffer for want of moisture and higher crop yields are expected. Crops sown beyond August may not be able to complete its life cycle as a result of inadequate moisture availability beyond 2nd fortnight of November (in the event of the intensity of northeast monsoon being low) as crop maturity coincides during this period. Under such circumstances, the short duration variety crops have to be preferred.

In a State like Karnataka having a spectrum of climates ranging from per humid type in the coastal and Malnad region to arid type in Bellary-Bijapur region, it is indicated that the Southwest monsoon rainfall is likely to be more uncertain with both increasing and decreasing trends in different parts of the state. Surface air temperature and diurnal temperature ranges are likely to increase along the high-ranges of the Western Ghats and under such conditions; there is a threat to thermo-sensitive crops like black pepper, cardamom, tea, coffee, cashew and other plantation crops. Frequent occurrence of droughts led to development of drought tolerant varieties to sustain agricultural production over the State. Unlike in other states, forest cover in Karnataka is increasing which is a positive sign. Karnataka State Action Plan on Climate Change was developed in the year 2012 which discusses climate trends, projected vulnerabilities along with adaptation and mitigation priorities for various sectors (EMPRI, 2012).

3.4 Climate Change Impacts on Crops

Rise in the mean temperature above a threshold level will cause a reduction in agricultural yields. A change in the minimum temperature is more crucial than a change in the maximum temperature. Grain yield of rice, for example, declined by 10% for each 1 °C increase in the growing season minimum temperature above 32 °C (Pathak *et al.*, 2003). Climate change impact on the productivity of rice in Punjab (India) has shown that with all other climatic variables remaining constant, temperature increases of 1 °C, 2 °C and 3 °C, would reduce the rice grain yields by 5.4%, 7.4% and 25.1%, respectively (Aggarwal *et al.*, 2009).

Field experiments and lab analyses were conducted at IARI, New Delhi in 2005, with five high-yielding rice varieties including aromatic and non-aromatic types, exposed to twelve different diurnal temperature (day/night) and radiation regimes to ascertain the impact of diurnal temperature and radiation changes on yield and yield components of aromatic and non-aromatic rice varieties in the field conditions and to document their effect on the grain and seed quality. Salient results indicate that the grain yield of all the five varieties was most significantly influenced by MNT ($P < 0.001$), followed by radiation ($P < 0.001$), explaining 87% and 77% of the yield variation respectively (Anand et al., 2015). Highest yields were recorded around a very narrow optimum temperature of 23°C to 24°C, with subsequent increase in temperature even by 1°C or 2°C, significantly reducing the grain yield.

General Circulation Models (GCMs) representing physical processes in the atmosphere, ocean, cryosphere and land surface are the most advanced tools currently available for simulating the response of the global climate system to increasing concentration of greenhouse gases. The GCMs depict the climate using a three-dimensional grid over the globe, typically having a horizontal resolution between 250 km and 600 km (approx. 2.5° × 2.5°). Their resolution is thus quite coarse relative to the scale of exposure units in most impact assessments. Regional climate models (RCMs) are run with the inputs from GCMs as well as from local topographical information. These models are of finer resolution, i.e., about 25 km × 25 km or less and thus are vital for regional impact assessments.

Simulation models are strong tools which provide opportunity to use various climate change scenarios in combination with different management parameters for analysing the regional impacts (Naresh Kumar and Aggarwal, 2009). Crop growth simulation models are used to quantify the impacts of elevated temperature, increased CO_2 level, change in rainfall, etc. individually or in combination. These analyses do provide vital information with reference to 'fixed changes in weather factors'. Another approach is to use the climate scenarios for impact assessments, wherein the global or regional climate model outputs of climate data are used as input for the crop simulation models to quantify the impacts. In fact, the research on climate change uses a cascade of simulation models (Naresh Kumar *et al.*, 2011).

3.4.1 Climate Change Impacts on Groundnut

Groundnut is the major oil seed crop in India and plays a major role in bridging the vegetable oil deficit in the country. Major groundnut growing states in India are Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka and Maharashtra and groundnut is grown mostly under rainfed conditions and sensitive to moisture stress at different phenological stages. Uncertainty of rains is one of the major constraints for rainfed groundnut production. A year receiving low or below normal rainfall need not result in low productivity and similarly a year receiving high rainfall may not produce higher crop yields; well distributed rainfall is the key for sustainable yields. Assessment of changes in duration and frequency of dry spells and wet spells in the groundnut crop-growing period due to climate change is important for planning and implementing suitable water management practices. Genetic coefficients for the groundnut variety ICGV 91114 were derived from the field experimental data. Daily observed weather data of ICRISAT Patancheru for 30 years (1985-2014) and DSSAT PnutGro model were used. Impacts of both 10-day and 15-day period water stress on groundnut were studied using PnutGRO model (Kesava Rao et al., 2015). Based on the future climate data sets, impacts of climate change on groundnut productivity at Patancheru were assessed.

Results indicated that a 15-day water stress period during 40-60 days after sowing (Fig. 3.2) would reduce yields significantly. If the water stress in this period is not properly managed, groundnut yields could be reduced by about 33 per cent of the rainfed potential yields.

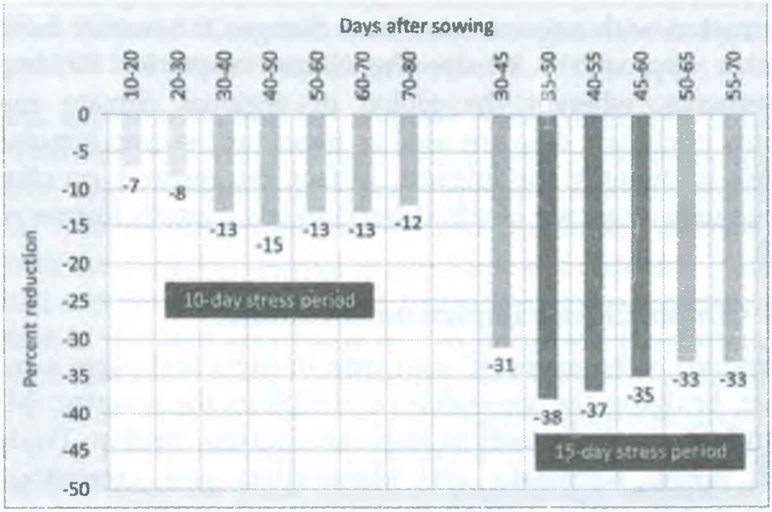

Fig. 3.2 Impact of water stress on groundnut pod yield

Current conditions (interpolations of observed data, representative of 1950-2000) and downscaled GCM data from Coupled Model Intercomparison Project Phase 5 (CMIP5) for three models (HadGEM2-ES, GFDL-CM3 and CNRM-CM5) were downloaded from the WorldClim – Global Climate Data portal for the whole world and from these datasets, representative data were extracted for the study location i.e., ICRISAT, Patancheru. These climate projections are for RCP 8.5 and for the year 2050 (2041 to 2060). Simulations with projected climate data (HadGEM2-ES, GFDL-CM3 and CNRM-CM5) indicated that groundnut pod yield would reduce by 9 to 13 per cent (Table 3.2).

Table 3.2 Impacts of projected climate on groundnut yields at ICRISAT

CC Scenario	Pod / Seed yield (kg ha^{-1})	Change in Pod / Seed yield (%)	Total Dry Matter production (kg ha^{-1})
Groundnut on Alfisols			
Current	2000	-	5430
HadGEM2-ES	1820	-9	5410
GFDL-CM3	1830	-9	5350
CNRM-CM5	1750	-13	5250

Simulations based on observed data have shown that if the water stress in this period is not properly managed, groundnut yields could be reduced by about 33 per cent of the rainfed potential yields.

3.4.2 Climate Change Impacts on Pigeonpea

Pigeonpea is the second most important pulse crop after chickpea in India. In 2010-11, it is cultivated in about 4.37 M ha (17% of the total area under pulses in the country) and contributs to about 16% to the total pulses production with an average productivity of 0.66 t ha^{-1}. In Karnataka, Gulbarga area is known as "Pulse Bowl of Karnataka". Pigeonpea area in Gulbarga has increased by three-folds from about 0.14 M ha in 1970 to 0.43 M ha in 2007. There has been a sharp and steady increase in area under pigeonpea since 1995. Average pigeonpea productivity, however, is low at about 0.42 t ha^{-1}. Pigeonpea productivity in Gulbarga is affected by large variations in rainfall amount and distribution, increased temperatures and depleting soil productivity. Genetic coefficients for the popular and promising pigeonpea variety TS-3R were estimated based on field experiments at ICRISAT, Patancheru.

Simulated pigeonpea grain yield and total biomass at Gulbarga were 2057 and 8708 kg ha^{-1}, respectively under baseline (present) climate. Increase in temperature by 1 and 2 °C could decrease grain yield by 9 and 16%, respectively (Table 3). Similarly, total biomass decreased by 5 and 9% with increase in the temperature by 1 and 2 °C. Decrease in rainfall by 10% coupled with increase in temperatures by 1 and 2 °C could further reduce grain yields by 5 and 4% making the total reduction at 14 and 20%. The situation could further worsen with reduction in rainfall by 20%, making the loss of grain yields by 21 and 28% with increase in temperature by 1 and 2 ^{o}C, respectively. Increased rainfall scenarios could benefit the crop to some extent, particularly in the low rainfall years, but net effect still remained negative.

Increased temperature could shorten the crop duration. Days to flowering shortened by 2 and 4 and the total crop duration by 5 and 9 days with increase in temperature by 1 and 2 °C, respectively. Increase in temperature causes more transpiration per day which results in water stress during the dry periods. Water balance outputs have shown that decrease in rainfall by 10 and 20% resulted in less plant water use by 18 and 45 mm, respectively with increase in temperature by 2 °C. Increments in rainfall by 10 and 20% are likely to result in more rainfall only for those days with rainfall and will not affect non-rainy days. Thus, additional rainfall has contributed more towards runoff and drainage than evapotranspiration. Simulated water use efficiency of pigeonpea reduced from 7.2 kg ha^{-1} mm^{-1} in the baseline by 6.6 and 6.0 kg ha^{-1} mm^{-1} with temperature increase of 1 and 2 °C, respectively. Better water and nutrient management approach is the key and Integrated Watershed Management plays a major role in sustaining pigeonpea productivity under future climate scenarios. Adoption of varieties tolerant to high temperature could also play a major role for sustainable pigeonpea yields. Water stress during the end of season could be avoided by sowing the short and extra-short duration varieties. Breeding of varieties which can put extra root mass is required for sustainable pigeonpea production.

Table 3.3 Effect of projected climate on phenology and productivity of pigeonpea cv. TS-3R

Climate scenario	Days to flower	Days to maturity	Total biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Change in yield (%)
Present (P)	103	157	8708	2057	0
P+1°C	101	151	8286	1875	-9
P+1°C-10%RF	99	150	7798	1771	-14
P+1°C-20%RF	99	150	7090	1615	-21
P+1°C+10%RF	101	151	8659	1961	-5
P+1°C+20%RF	101	152	8866	2005	-3
P+2°C	99	148	7943	1734	-16
P+2°C-10%RF	98	147	7465	1636	-20
P+2°C-20%RF	98	147	6763	1486	-28
P+2°C+10%RF	100	149	8302	1809	-12
P+2°C+20%RF	99	148	8525	1854	-10

Climate change affects dynamics and interaction among species and it will affect and change the pattern of pest damage and pest control strategies. Increase in temperature may increase the need for application of pesticides and may reduce pesticide effectiveness and increase residues. Rao *et al.* (2009) have conducted feeding trials with two foliage feeding insect species, *Achaea janata* and *Spodoptera litura* using foliage of castor plants grown under four concentrations of CO_2, viz. 700 ppm CO_2 inside open top chamber (OTC), 550 ppm CO_2 inside OTC, ambient CO_2 (350 ppm) inside OTC and ambient CO_2 in the open. Biochemical analysis of the foliage revealed that plants grown under the elevated CO_2 levels had lower N-content, and higher C-content, C/N ratio and polyphenols. Compared to the larvae fed on the ambient CO_2 foliage, the larvae fed on 700 ppm and 550 ppm CO_2 foliage exhibited higher consumption. The 700 ppm and 550 ppm CO_2 foliage was more digestible with higher values of approximate digestibility. The relative consumption rate of larvae increased, whereas the efficiency parameters, viz. efficiency of conversion of ingested food (ECI), efficiency of conversion of digested food (ECD) and relative growth rate (RGR) decreased in the case of larvae grown on 700 ppm and 550 ppm CO_2 foliage. The consumption and weight gain of the larvae were negatively and significantly influenced by the leaf nitrogen, which was found to be the most important factor affecting consumption and growth of larvae.

Using the 'Rice FACE' facility in northern Japan, Kobayashi *et al.* (2006) studied the effect of 200–280 ppm above-ambient CO_2 on rice blast and sheath blight disease for three seasons. Severity of leaf blast (*Magnaportheoryzae*) was consistently higher at the elevated CO_2 levels in all the three years assessed at two different stages of rice growth.

3.5 Food Grain Production Trends

From a net importer of food in 1950s, India has transformed itself in the production of food grains (mainly rice, wheat, coarse cereals and pulses) during the last few decades. From a mere 50 million tons (mt) of annual food grain production in 1950s, India in 2012-

13 has produced 257 mt of food grains, mainly attributed to the significant jump in rice and wheat output. The average growth rate of food grains production from 1950 to 2011 was 3.2% per annum. Overall, wheat was the best performer, with production increasing from mere 6.6 mt in 1950-51 to 90 mt during 2011-12, a huge jump. Wheat was followed by rice, which had a production increase from 20 mt to 102 mt. Total food grains production in India, Andhra Pradesh, Karnataka and Telangana are shown in the figures 3.3, 3.4, 3.5 and 3.6. It is seen that both India as a whole and Andhra Pradesh show consistent increase in productivity, it appears that in Karnataka it varied from about 1 to 1.8 tonne per hectare. In Telangana, the productivity has shown great improvements in the recent years even touching 3 tonne per hectare.

Cereals productivity in Northern Karnataka is very low; since large areas are under cultivation, there is great potential for improvement. Pulses productivity levels are far below their potential. Except the three northern districts (Bidar, Bijapur and Gulbarga), cultivation of pulses is very low. Crop rotations with pulses will improve overall food grain productivity in Karnataka.

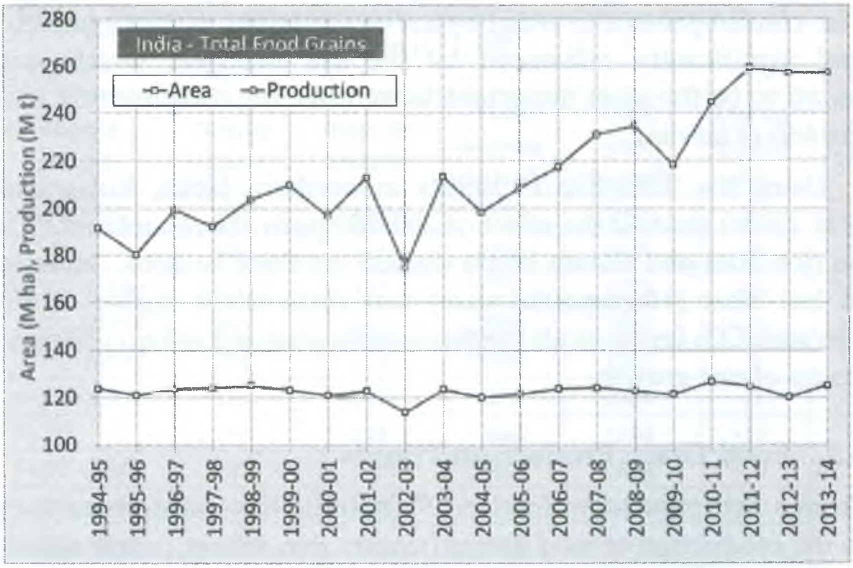

Fig. 3.3 Variability in area and production of total food grains in India

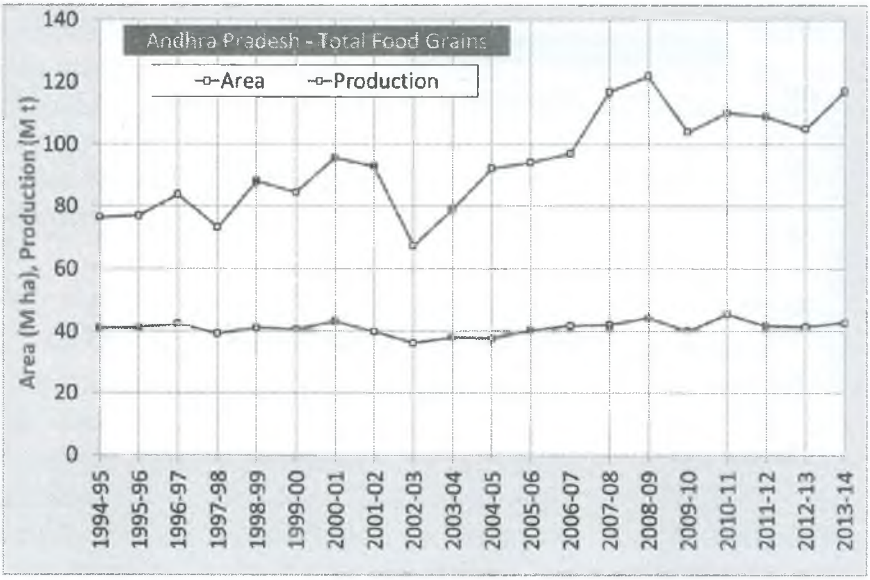

Fig. 3.4 Variability in area and production of total food grains in Andhra Pradesh

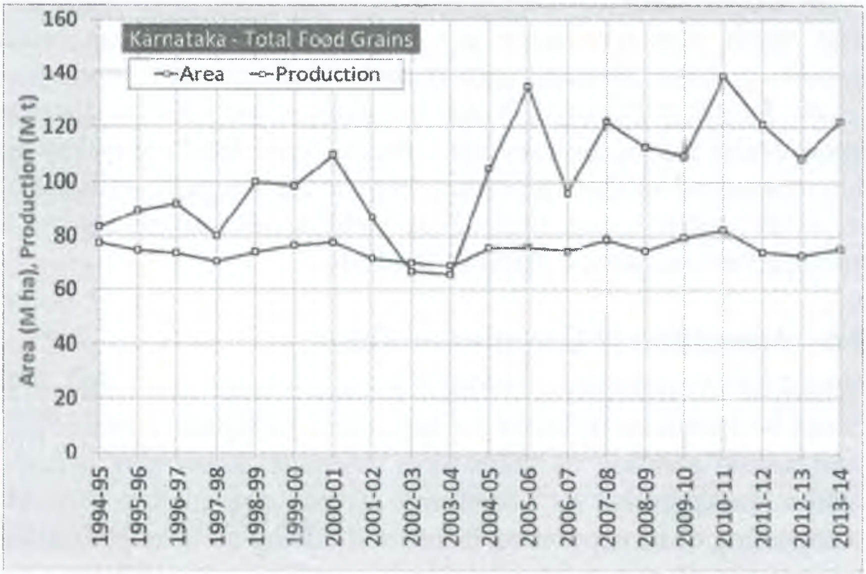

Fig. 3.5 Variability in area and production of total food grains in Karnataka

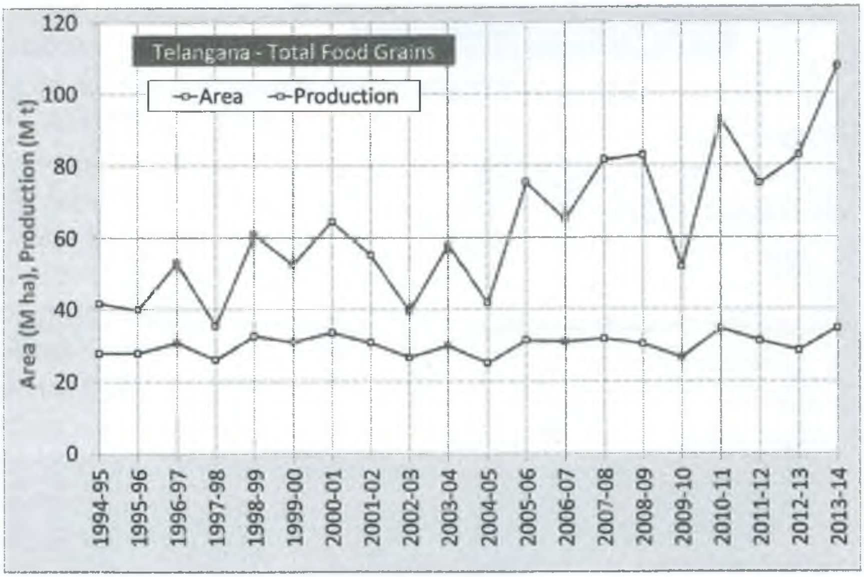

Fig. 3.6 Variability in area and production of total food grains in Telangana

While in Andhra Pradesh, cereals yield levels in Rayalaseema and north coastal districts are low. Considerable areas under cereals in these districts give scope to enhance the production levels. Except in Kurnool, Prakasam, Guntur and Krishna districts, areas under pulses are very low. Productivity levels of pulses are low compared to their potential. Expanding the pulse cultivation in other districts and improving yield levels are necessary to achieve food security in Andhra Pradesh.

3.6 Mitigation of Greenhouse Gases

Strategies for mitigating methane emission from rice cultivation could be alteration in water management, particularly promoting mid-season aeration by short-term drainage; improving organic matter management by promoting aerobic degradation through composting or incorporating it into soil during off-season drained period; use of rice cultivars with few unproductive tillers, high root oxidative activity and high harvest index; and application of fermented manures like biogas slurry in place of unfermented farmyard manure (Pathak and Wassmann, 2007). Methane emission from ruminants can be reduced by altering the feed composition, either to reduce the percentage which is converted into methane or to improve the milk and meat yield. The most efficient management practice to reduce nitrous oxide emission is site-specific, efficient nutrient management (Pathak, 2010). The emission could also be reduced by nitrification inhibitors such as nitrapyrin and dicyandiamide (DCD).

3.7 Leaf Colour Chart for Site-Specific Nitrogen Management

Leaf Colour Chart (LCC) is an easy-to-use and inexpensive tool for determining nitrogen status in plants. Use of the LCC promotes timely and efficient use of N fertilizer in rice and wheat to save costly fertilizer and minimize the fertilizer related pollution of surface water and groundwater. It is a promising eco-friendly and inexpensive tool in the hands of the farmers.

3.8 Climate Projections (IPCC AR5)

Approved summary for the Working Group I of the IPCC indicates that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. Total radiative forcing is positive, and has led to an uptake of energy by the climate system. Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions.

3.9 Adaptation Strategies for Climate Resilience

There is a need to understand the shifts in climate at different agro-eco regions in SAT India in terms of anticipated shifts in the crop growing periods and water availability and to use the results of agroclimatic trend analysis to device suitable adaptation strategies. Increased dependence on groundwater irrigation and indiscriminate usage of chemical fertilizers for increasing crop productivity will not be sustainable in the future. Under the future likely climate change scenario, this situation would worsen jeopardising the long-term perspective of livelihoods of the great majority of the rural population.

Resilience to climate change depends on identifying climate smart crops and management practices and degree of awareness of community. Knowledge dissemination to farmer about climate change is critical. The present weakest link of knowledge dissemination needs to be strengthened. Innovative participatory delivery systems using ICT mediated climate early warning systems and weekly agromet advisories would empower farmers of Karnataka to take smart and swift decisions and make them resilient and food secure. There is a need for scaling up the integrated climate smart agricultural practices for bringing in resilience. Social safety nets along with adaptation strategies are needed. Another major activity required under crop insurance scheme is to identify the weather based indices for various rainfed crops and varieties.

Intercropping with grain legumes is one of the key strategies to improve productivity and sustainability of rainfed agriculture. Productive intercropping options identified to intensify and diversify rainfed cropping systems are:

- Groundnut with maize
- Pigeonpea with maize
- Pigeonpea with soybean

Some of the other initiatives are ridge planting systems; seed treatment; Integrated Pest Management (IPM); adoption of improved crop varieties and production technologies; promoting community-based seed production groups and market linkages. Farmers need to be encouraged to practice seed treatment with Trichodermaspp and fungicides for managing seedling diseases and IPM options for controlling pod borer in chickpea and pigeonpea.

3.9.1 Polythene-lined Water Storage Ponds in Karnataka

About 35,000 farmers across the Karnataka state's 175 taluks are implementing the pilot programme by setting up polythene-lined water storage ponds in their fields to prevent water seepage and store run-off rainwater. The intent is to ensure that the dryland farmer has at least some water to ensure that their entire crop is not ruined, either through excess rain or due to drought, said by Karnataka's minister of state for agriculture, Krishna Byre Gowda. All of them have individual or jointly-owned diesel pumps that will provide micro irrigation (drip irrigation) from the poly ponds for their fields. It is being piloted for the kharif season 2015 that began in April and will go on until September. Another 1,750 farmers have opted for more high-end poly houses - poly roofs over a section of their farms - to grow exotic vegetables under shade, which will ensure that they won't fall into debt under any circumstances, be it excess or deficit rain.

3.9.2 Poly Mulching Technology for Better Quality Tomato

Summer season is a time of worry for most farmers across the country since water becomes an important, and much sought after commodity. Though water harvesting and conservation are being encouraged by the government the number of farmers adopting it is still quite negligible in the country. Small farmers cannot afford to dig a small pond to collect rainwater since it eats away into their cropping area. For such growers, the Krishi Vigyan Kendra (KVK) under the Indian Institute of Horticultural Research (IIHR, Bangalore) at Hirehalli, Tumkur, Karnataka, initiated demonstrations to popularize the practice of poly mulching technology in the region. The sheets are laid on the field by a machine on top of the furrows and seedlings are planted in small holes made on the sheets. Plastic sheets have been found to conserve soil moisture because the water that gets evaporated from the soil in the open will condense on the lower part of the sheet as small droplets and falls back into the soil.

A small farmer, Ms Saroja, from Deverayanapatna village in Tumkur taluk, with having two acres of land was encouraged to grow the tomato variety ArkaSamrat released by IIHR under this technology. The normal duration of this variety is 135-140 days only but due to the impact of polythene mulching, the crop period extended to 10-15 days more. The tomato seedlings were grown on raised beds with poly mulch film laid with drip irrigation. A package of practices like mulching was suggested which minimised the incidences of pests and viral diseases as reported by The Hindu on 30 July 2014.

The fruits obtained are of better quality and colour, which fetch better price in the market. The farmer harvested nearly 32 tonnes from an acre in 150 days and sold them at Rs.10 per kg in the local market. She earned a gross profit of Rs. 3.25 lakhs in 150 days. Total cost of cultivation was Rs. 60,000 per acre and the farmer earned a net profit of Rs. 2.65 lakhs in five months.

3.10 ICRISAT's Hypothesis of Hope to Address Climate Variability and Change

ICRISAT's research findings showed that Integrated Genetic and Natural Resources Management (IGNRM) through participatory watershed management is the key for improving rural livelihoods in the SAT (Wani *et al.*, 2002, 2003 and 2011). Even under a climate change regime, crop yield gaps can still be significantly narrowed down with improved management practices and using Germplasm adapted for warmer temperatures (Wani *et al.*, 2003, 2009 and Cooper et al., 2009). Some of the climate resilient crops are short-duration chickpea cultivars ICC 96029 (Super early), ICCV 2 (Extra-early) and KAK 2 (Early maturing); wilt resistant pigeonpea hybrid (ICPH 2671) with a potential to give 80% higher yields than traditional varieties and short-duration groundnut cultivar ICGV 91114 that escapes terminal drought.

Integrated Watershed Management comprises improvement of land and water management, integrated nutrient management including application of micronutrients, improved varieties and integrated pest and disease management for substantial productivity gains and economic returns by farmers (Wani *et al.*, 2003). The goal of watershed management is to improve livelihood security by mitigating the negative effects of climatic variability while protecting or enhancing the sustainability of the environment and the agricultural resource base. Greater resilience of crop income in Kothapally (Andhra Pradesh) during the drought year 2002 was indeed due to watershed interventions. While the share of crops in household income declined from 44% to 12% in the non-watershed project villages, crop income remained largely unchanged from 36% to 37% in the watershed village (Wani et al., 2009).

Agroclimatic analysis coupled with crop-simulation models, and better seasonal and medium duration weather forecasts, help build resilience to climate variability/ change in watersheds. This means that high yields are still possible under variable climate if farmers combine improved practices with climate-adapted crop varieties. Hence, the challenge today is to encourage rainfed farmers to adopt these improved options to increase productivity and profitability of their crops, and to become more resilient under climate variability. Farmers need to be encouraged to enhance soil quality and fertility through composting of organic wastes; and to promote cultivation of Leucaena, *Hardwickiabianta* and Glyricidia on farm bunds. Governments may also consider promoting and incentivizing the soil and water conservation measures taken by farmers. An improved agromet advisory service at the local level along with associated weather insurance packages is a sure way to enhance the resilience of poor farmers in the context of climate change. Policy interventions are needed to mitigate the climate change effects and Governments have to be proactive in developing adaptation strategies for those sectors like agriculture, water resources, forestry and biodiversity which are highly exposed to the future climate changes and have a significant impact on livelihoods.

Enhancing resilience through climate smart agriculture

ICRISAT's findings show that even under a climate change regime, crop yield gaps can still be significantly narrowed down with improved management practices and using Germplasm adapted for warmer temperatures. As an adaptation strategy to climate variability/change and in rainfed areas, ICRISAT has recommended the cultivation of climate resilient crops, such as short-duration chickpea cultivars, wilt resistant pigeonpea hybrids and short-duration groundnut cultivar ICGV 91114 that escapes terminal drought. Chickpea is traditionally grown in the relatively colder northern India during the dry winter season with temperatures of 20-30 °C and traditional chickpea varieties are of

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long duration (more than 120 days) and not very suitable for Andhra Pradesh. Ten years ago, only 160,000 hectares of chickpeas were grown in AP and the yield was only 600 kg ha^{-1}. Introduction of improved varieties of chickpea like JG11, *Swetha* (ICCV 2) and *Kranthi* (ICCC 37), which are resistant to higher temperature and wilt disease has changed the situation and the area under chickpea cultivation increased to 630,000 hectares and average yield increased from 600 to 1,400 kg ha^{-1}.

The community-based management of natural resources calls for new approaches (technical, institutional and social) which are knowledge-intensive and need strong capacity development measures for all the stakeholders including policy makers, researchers, development agents, and farmers. We need to connect the small and marginal farmers to the new knowledge and materials produced by the researchers.

ICRISAT's principle to improve the livelihoods of small-holder farmers even under future climate change scenario is built on the concept of Inclusive Market Oriented Development (IMDO), which is a Dynamic Development Pathway consisting of innovative environment, inclusive and market oriented.

In the years with aberrant weather, even the landless households face loss of employment opportunities and many of them may have to migrate to longer distances in search of employment opportunities. Production uncertainties also depress the prospects of trade and services. In short, the entire rural economy is highly vulnerable to the risks associated with climatic variability and possible climate change. Inputs of knowledge-intensive institutions like research, extension and development organizations become critical in enhancing the resilience of rural people to cope with the changing climatic patterns.

Weather based Crop Insurance Scheme (WBCIS) provides insurance protection against losses in crop yield resulting from adverse weather conditions. It provides pay-out against adverse rainfall incidence (both deficit & excess) during *Kharif* and adverse incidence in weather parameters like frost, heat, relative humidity, unseasonal rainfall etc. during *Rabi*. It is not yield guarantee insurance and is different from the National Agricultural Insurance Scheme (NAIS). One key advantage of the weather risk based crop insurance is that the pay-outs could be made faster, besides the fact that the insurance contract is more transparent and the transaction costs are lower. Under the changing climates, a key-challenge in designing insurance is to transfer risk and incentivize risk reduction through price incentives and risk management stipulations. Without this complementary risk reduction, more risks could become uninsurable in the future.

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