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Assessment of the impact of increasing temperature and rainfall variability on crop productivity in drylands - An illustrative approach

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N. Manikandan, S.B.S.Narasimha Rao, V.U.M. Rao
and B. Venkateswarlu

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PREFACE

Climate variability and it's impact on agriculture has become a prime concern of the country as majority of Indian farmers are vulnerable to climatic change. Projections of the future climate and consequent changes in crop yields using crop growth models were attempted by several workers all over the world. These models involve a lot of empiricism or in-built assumptions. Many of the processes simulated in these crop models do not account for the complexity of natural variables, and the crop genetic adaptability. In this context, it is worthwhile to examine the crop / genetic responses to climate variability using real time data as they involve the response of the genotype to complex environmental interactions.

The intra seasonal variability in crop yields is largely driven by the two parameters, rainfall and thermal regime in tropical dryland areas. The relative impact of these two parameters on crop productivity was not evaluated systematically. Therefore, a study was undertaken to assess the impact of varying rainfall and increasing seasonal temperature on the productivity of groundnut grown under rainfed conditions at Anantapur representing a typical arid region in Peninsular India. The methodology attempted to isolate the impact of variability in rainfall regime and increasing temperature individually and in combination provides an opportunity to identify the research and extension priorities required to deal with the problem of climatic variability and probable adaptation strategies.

Suggestions and comments on the proposed methodology attempted in this bulletin will be appreciated.

(B. Venkateswarlu)

Hyderabad
08.08.2011

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1. INTRODUCTION

Inter-annual variability in yields of rainfed crops is often attributed to changes in the weather conditions form year to year. Therefore, research efforts in dryland agriculture were focused hither to on developing cropping strategies and management practices in accordance with the variability in seasonal rainfall and other weather parameters. Of late, there is growing awareness on changes in global climate and its impact on agriculture. Scientists from all over the world have started analyzing historical weather data for different locations to examine

- climatic variability form year to year
- cyclic effects on climatic variability, and
- trends in climatic variability

There were evidences that there is an increasing trend in global temperatures during the last hundred years although the magnitude of increase is not exactly the same in all the regions. Rapid industrialization, increased use of fossil fuels, destruction of native vegetation to bring more area under cultivation to meet the growing requirement of food have all contributed to increased greenhouse gases, atmospheric pollution and consequent changes in the world climate.

The major cause to climate change has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), chlorofluorocarbons (CFCs) due to burning of fossil fuels, increased use of refrigerants, and chemical based agricultural practices. These activities accelerated the processes of climate change and increased the mean global temperatures by 0.6°C during the past 100 years. It has also induced increased climatic variability and occurrence of extreme weather events in many parts of the world. Studies indicate that the recent years viz., 1997, 1998 and 1999 have been among the warmest during the past century and the process continued into the 21st century and the year 2010 was declared as the third warmest year since 1860, the period for which instrumental records are available. According to IPCC (2007), the 21st century is projected to experience 1.8 to 4.0 ^{o}C rise in surface air temperature together with very likely occurrence of frequent warm spells, heat waves and heavy rainfall and a likely increase in the frequency of droughts.

Climate change scenarios for the Indian subcontinent as inferred by Lal (2001) from simulation experiments using atmosphere-ocean GCMs under the fourth Special Report on Emission Scenarios (SRES) marker scenarios suggest an annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5°C over the region by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution of surface warming suggest a mean annual rise in surface temperatures in north India by 3°C or more by 2050. The study also suggests that during winter, the surface mean air temperature could rise by 3°C in northern and central parts while it would rise by 2°C in southern parts by 2050. In case of annual rainfall, a marginal increase of 7 to 10 per cent is projected over the sub-continent by the year 2080. The study further suggests a decline in rainfall by 5 to 25 per cent in winter while it would be 10 to 15 per cent increase in summer monsoon rainfall over the country.

1.1 Crop growth models *vis-a-vis* Climate change

Crop growth models are widely used to simulate the impact of climate change on various crops such as rice (Tao *et al*., 2008), wheat (Hundal and Prabhajyot-Kaur, 2007, Chapman, 2008), groundnut (Challinor *et al*., 2007; Challinor and Wheeler, 2008) sorghum (Zeng and Heilman, 1997, Tingem and Rivington, 2009; Srivatsava *et al*., 2010) and maize (Xiong *et al*., 2007; Almaraz *et al*., 2008). In most of these studies, models are used to assess the crop response to changes in atmospheric CO_2 and rise/fall in temperature. For example, groundnut yields were simulated by INFOCROP model (Anonymous, 2010) under elevated temperatures (up to +3.5 ^{o}C) and elevated CO_2. The model projected that groundnut shows greater thermal sensitivity during reproductive growth phase followed by vegetative growth phase. The crop subjected to elevated temperature for the entire growth period showed additive detrimental effect of high temperature during vegetative and reproductive growth phases. Reduction in groundnut yields were attributed to drastic reduction in nuts per sq m, 1000 seed weight and biomass. Groundnut responded positively to elevated CO_2 (560 ppm) which was again attributed to marked increase in biomass and nuts per sq m. These models have inherent empiricism and assumptions that they often fail to take into account the interactive effects of more than one variable that occur in nature.

Climates all over the world are classified based on thermal regime and moisture regime as both these factors have profound influence on the native vegetation, agricultural production systems and their productivity. Thus, the crop response to variable and changing climate has to be examined considering the variability in thermal and moisture regimes together using real time crop data. Such an approach may be helpful in assessing the factors that govern the changes in crop productivity from year to year and to identify research priorities to sustain and stabilize agricultural productivity in drylands.

In order to assess the impact of changing thermal and moisture regimes on crop productivity under rainfed conditions an analytical approach can be attempted using real time data. To illustrate this approach, the variation in productivity of groundnut grown under rainfed conditions in Anantapur region of Andhra Pradesh was used an as example. The site was chosen because of its high inter-annual variation in rainfall (a 40-year mean of 572 mm with a standard deviation of 200 mm) to ensure crop seasons of contrasting water regimes.

2. STUDY AREA

Anantapur district lies between 13°40' and 15°15' Northern Latitude and 76°50' and 78° 30' Eastern Longitude (Fig 2.1). Anantapur is having a geographical area of 19,13,000 ha with nearly 13 per cent of the district's area under forests. Gross cropped area is 11,36,000 ha and the net sown area accounts for 69.6 per cent of the total geographical area. The district has a cropping intensity of 106 per cent. Only 10.5 per cent of the area is under non-agricultural uses while permanent pastures constitute 2.2 per cent. Anantapur is the only arid district of the Andhra Pradesh state with only 572 mm annual rainfall. This district lies in the rain shadow area of the state and suffers from frequent droughts. It has only 10 per cent of area under irrigation with groundnut occupying maximum area under rainfed condition accounting for over 75 per cent of the cropped area. Other important crops are sunflower (6.4%), gram (4.9%), pigeonpea (3.6%), rice (3.4%) and sorghum (2.2%). The productivity of the major crops is less than half a ton per hectare reflecting the harsh production environment in the district.

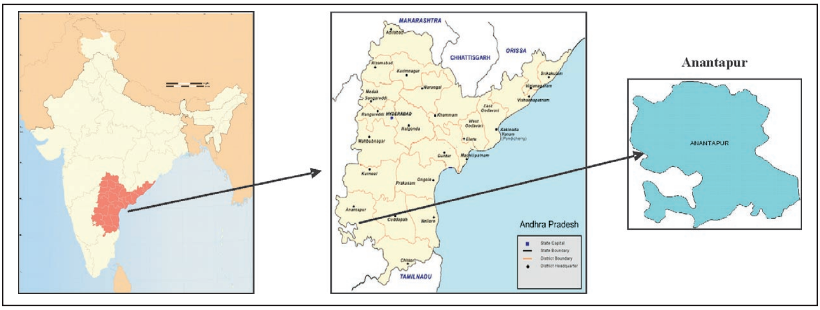

Fig 2.1: Location map of study area

2.1 Climate change scenarios

The climate scenario for Anantapur district as projected by National Communication (NATCOM, 2009) under A1b scenario suggests that compared to base line (1961-1990), the rainfall is going to decrease by about 14.4 per cent by 2021-2050 period and by 8.7 per cent during 2071-2098 period (Fig. 2.2). The south-west monsoonal rainfall (June-September) is projected to decrease by 17 per cent by 2021-2050 and by 29.4 per cent during the 2071-2098 period. The severity of drought during July and September months of 2021-2050 period may be of concern as 20 per cent and 30.8 per cent decline, respectively, are projected. The scenario during 2071-2098 for the month of July is further worse with a projection of 39.6 per cent decline from the base period 1961-1990. The deficit is projected to be continued in the month of September with 31 per cent decrease during 2021-2050 that was projected to improve marginally to a decline of 18.6 per cent by 2071-2098 period. The December to March rainfall showed significant increased trend in both the scenarios. Though small in amounts, the rainfall projections during December-March period may help during the critical periods of *rabi* crops leading to enhanced yields. A change in the cropping pattern is in offing.

2.1.1 Maximum temperature

The mean annual maximum temperature during the period 2021-2050 is projected to increase by 2.8°C and further to 4.7°C by 2071-2098 (Fig.2.3). The mean maximum temperature during the southwest monsoon season is likely to increase by 2.3°C during 2021-2050 period and by 4.8°C during 2071-2098 period. The *rabi* (post monsoon) season mean maximum temperature is projected to increase by 3.9°C during 2021-2050 and which may further rise by 5.2°C during 2071-2098 period. The summer months of April and May are likely to experience a 2.8°C rise in mean maximum temperature during 2021-2050 and the temperature is likely to rise by 4.8°C by 2071-2098 period.

2.1.2 Minimum temperature

The mean annual minimum temperatures are likely to rise by 2.9°C during the 2021-2050 period and by 5.2°C during 2071-2098 (Fig.2.4). The mean minimum temperature during the southwest monsoon season is likely to increase by 2.2°C during 2021-2050 and by 4.2°C during 2071-2098. The *rabi* (post monsoon) season mean minimum temperature is projected to increase by 3.4°C during 2021-2050 and which may further rise by 5.9°C during 2071-2098 period. The summer months of April and May are likely to experience a 2.9°C rise in mean minimum temperature during 2021-2050 and the temperature is likely to rise by 5.3°C by 2071-2098.

Groundnut is the principal *Kharif* crop of the Anantapur district cultivated over an area of about 8 lakh ha. The area under this crop

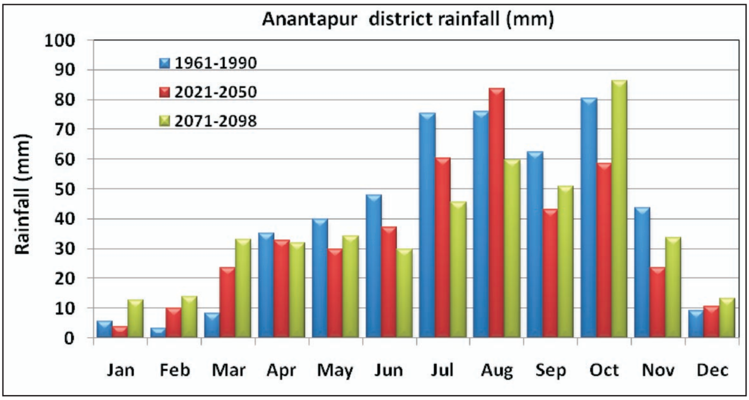

Fig 2.2: Baseline (1961-1990) and projected rainfall pattern in A1b climate change scenario (NATCOM)

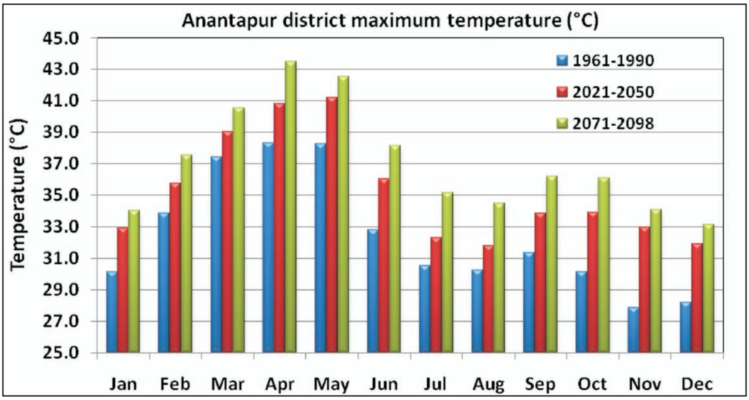

Fig 2.3: Anticipated changes in maximum temperature in future A1b climatic scenario (NATCOM)

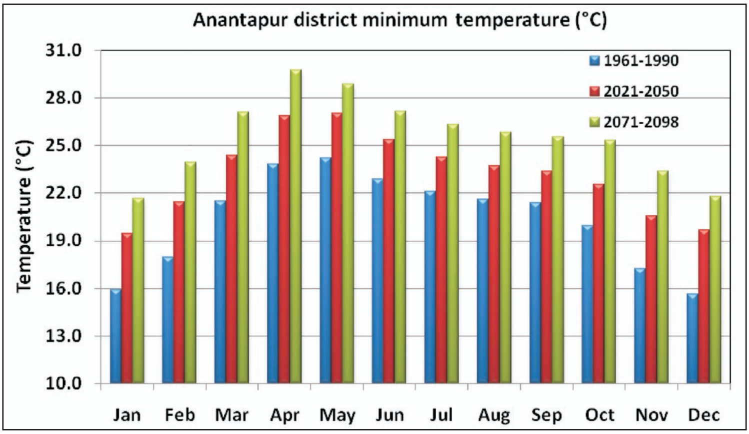

Fig.2.4: Anticipated changes in minimum temperature in future A1b climatic scenario (NATCOM)

increased from 2.5 lakh ha in 1970's to 8 lakh ha by 2000. The average productivity is 730 kg/ha and large year to year fluctuations are noticed in the productivity. Highest productivity (1328 kg/ha) was recorded in 1996 and lowest yield (67 kg/ha) was recorded in 2006 (Fig 2.5). Quantum and distribution of rainfall determines the productivity of groundnut to a large extent. Piara Singh *et al*., (1994) opined that rainfall is a major factor causing spatial and temporal variations in groundnut yields. Temperature is another dominant factor controlling the rate at which groundnut develops (Cox, 1979). In terms of plant growth and development, the diurnal temperature cycle is more important than

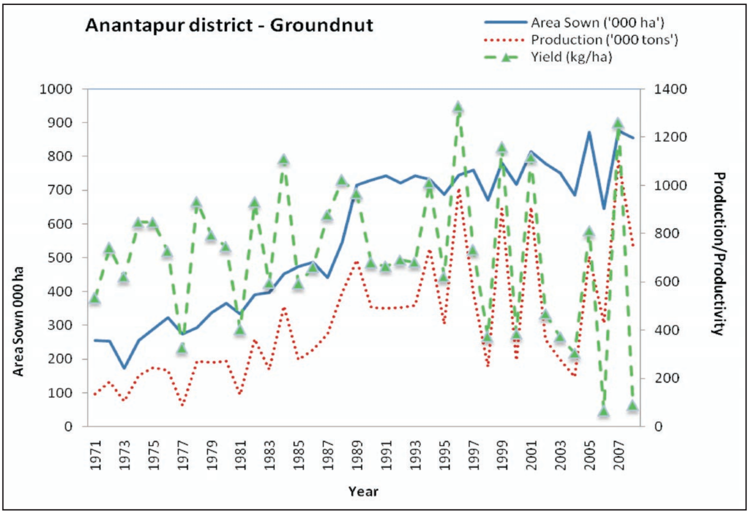

Fig 2.5: Trends in area, production and productivity of groundnut in Anantapur district

either the regular seasonal cycle or the random effects of weather in the SAT (Monteith, 1977). To understand the climate change effects on groundnut, the response of the crop need to be assessed in terms of temperature increase and rainfall variability. Monteith (1981) calculated in an earlier study the contribution that different weather factors have on yields of winter and spring sown crops of eastern England. He concluded that the two largest climatic causes of variation in yield were temperature and rainfall and their independent effects were three to four times larger than caused by variation in how much light was incident on crops. About 12 per cent yield variation in winter cereals on heavy soils was calculated to stem from variation in temperature, radiation and rainfall. This rose to 17 per cent of the yield variation on lighter soils.

Rainfall is the most significant climatic factor affecting crop production in the SAT because most crops are rainfed. However, the relationship between groundnut yield and seasonal rainfall is often poor (Popov, 1984). A comparison of groundnut yields at Bambey, Sengal for 32 years showed fourfold changes at a seasonal rainfall of 800 mm.

Groundnut yields in Anantapur district were simulated under A1 and B2 scenarios of IPCC using Integrated Modelling System (IMS) approach for the period 2071 to 2100 (World Bank, 2008). The model predicts an average increase in annual precipitation of about 8 per cent in the A2 scenario and 4 per cent in the B2 scenario. An increase in the annual minimum temperature in the range of 2.5°C (B2) to 3.4°C (A2) and maximum temperature in the range of 2.3°C (B2) to 3.1°C (A2) is observed. The rainfall pattern is also projected to change as the traditionally wetter months of June and July are expected to receive less rainfall, and the dry months of May, September and October months would receive marginally increased rainfall amounts. Despite a slight increase in rainfall, groundnut yields were projected to decrease dramatically in A2 scenario by 28 per cent and modestly in B2 scenario by 6 per cent.

Assessment of climate change impacts on groundnut yield using INFOCROP model at Indore, Anantapur and Anand locations for 2021-2050 and 2071-2100 periods under A1b, B2 and A2 scenarios resulted in significant increase in crop season mean air temperature as compared to baseline (1961-1990) temperatures. The rise in temperature ranged from 1.8 to 5.1°C in different scenarios and for different time periods. Increase in rainfall amounts to a tune of 10 to 25 per cent was also projected in different scenarios and time periods. A four to seven per cent increase in rainfed groundnut yields were projected except for A1b scenario for 2071-2100 period wherein the yield was projected to decline by five per cent. Across the locations the rainfed groundnut yields showed significant positive association with seasonal rainfall but poor or non-significant association was noticed with crop season mean air temperature (CRIDA, 2010).

Increased variation and changes in mean temperature and precipitation are expected to dominate future changes in climate as they affect crop production. The abundance radiation in semi-arid tropics drove the investigators to consider only the influence and temperature and rainfall on groundnut yields.

3. METHODOLOGY

3.1 Data utilized

The pod yield data of groundnut from the field experiments conducted under the aegis of All India Co-ordinated Research Project on Agrometeorology at Agricultural Research Station, Anantapur for the period 1985-2010 (26 years) was utilized in this study. Groundnut c.v TMV-2 was raised under rainfed conditions on sandy loam soils with adequate nutrition (20-40-50 kg N, P_2O5 and K_2O per ha) at 30 x 10 cm spacing. The soil of the test site has pH of 5.8 with 0.27% organic carbon. The soil is poor in fertility with 103 kg available K_2O, 76 kg nitrogen but with high P_2O (118 kg/ha). All the recommended cultural practices were adopted to maintain a good crop condition. The meteorological data recorded in the Meteorological observatory very close by was used in determining the weather scenarios.

3.2 Climate of the study area

The climates are generally classified using the concept of moisture index (Thornthwaite, 1948), which can be calculated using the formula:

$$Im = (P-PET)/PET \times 100$$

where, P is Annual precipitation (mm)

PET is Annual potential ET (mm) and

Im is Moisture Index

If the moisture index is less than -66.7 per cent then the climate is classified as arid and if its value is between -33.4 to -66.6 per cent it is classified as semi-arid climate. The value of Im for the years 1971-2010 is shown in Fig. 3.1.

The average value of Im at Anantapur for the corresponding period is -71.9 per cent. From the Fig 3.1, it can be clearly seen that the year to year variability in climate fluctuations place this district from arid to semi-arid conditions although it is predominantly an arid area.

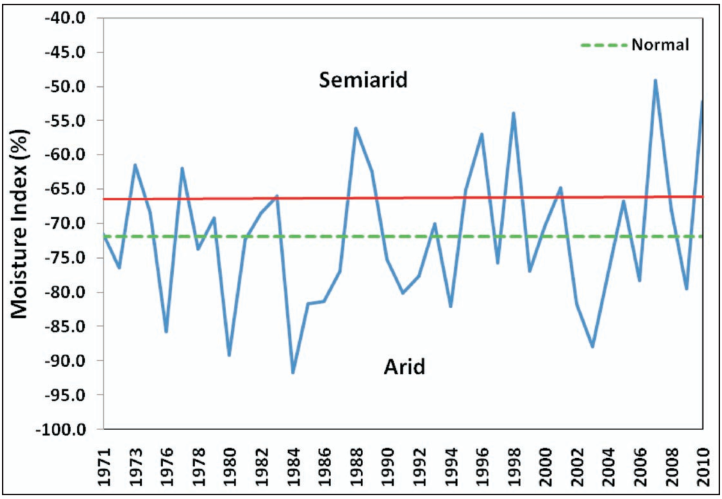

Fig.3.1: Variations in annual moisture index at Anantapur (1971 - 2010)

3.2.1Annual rainfall

The average annual rainfall (Fig.3.2) at Anantapur is 572 mm with a standard deviation (σ) of 200 mm. The rainfall was near and above average for 19 years out of 40 years considered.

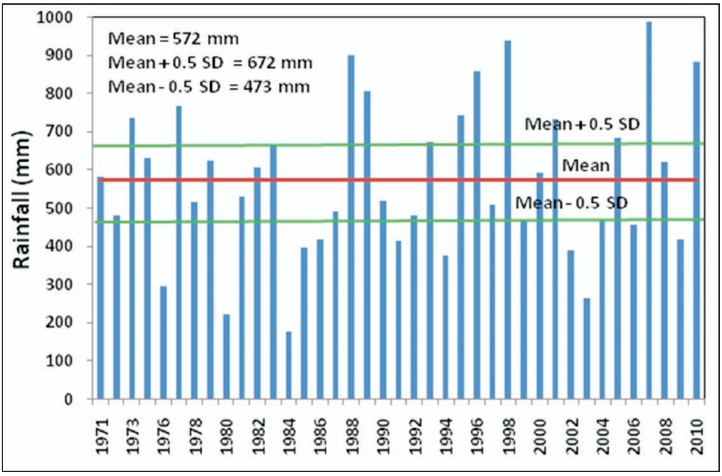

Fig.3.2: Variations in annual rainfall at Anantapur (1971 - 2010)

3.2.2 Weekly rainfall

The distribution of mean weekly rainfall at Anantapur for the Meteorological Standard Weeks (MSW) 1 to 52 is shown in Fig 3.3. From the figure it can be understood that the crops can be grown in Anantapur region under rainfed conditions from 29th MSW onwards, such that the crop will receive peak rainfall during reproductive stage from MSW 39. Therefore farmers usually prefer cultivation of groundnut under rainfed conditions from 29th MSW onwards. The crop is generally sown at the earliest opportunity with the receipt of rains during 2nd fortnight of July. The cultivation of groundnut is preferred in this region as groundnut can withstand dry spells of 4 to 6 weeks duration during its vegetative growth phase. Occurrence of rainfall during first flowering and pod development stages is very crucial for higher productivity of the crop.

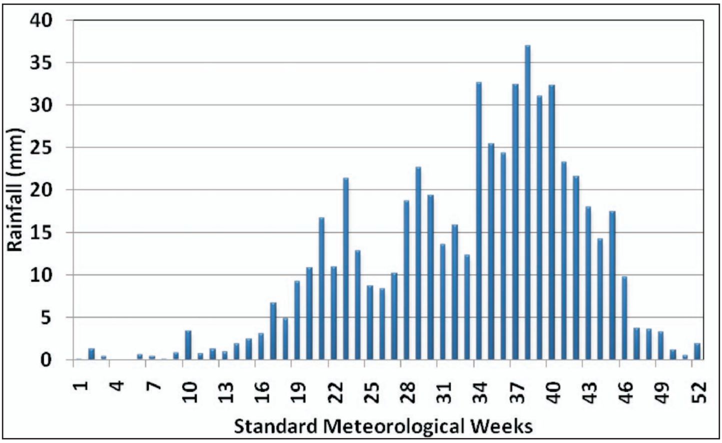

Fig.3.3: Normal weekly rainfall at Anantapur (1971 – 2010)

3.2.3 Rainfall during cropping season

The average seasonal rainfall ($\bar{X}$) during the cropping season (29-46 MSW) is 398 mm with a standard deviation (σ) of 158 mm as shown in Fig 3.4. Therefore, the rainfall regime at Anantapur was classified in the present analysis into three groups.

- Group I : $>\bar{X} + 0.5\,\sigma$ (> 477 mm)
- Group II : $\bar{X} + 0.5\,\sigma$ to $X - 0.5\,\sigma$ (319-477 mm)
- Group III : $< \bar{X} - 0.5\,\sigma$ (< 319 mm)

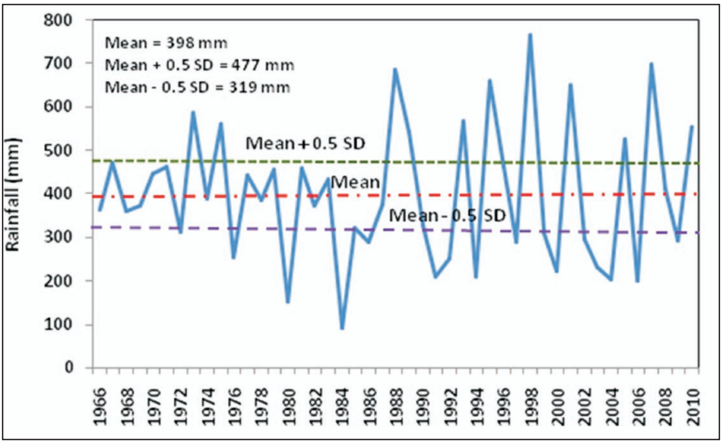

Fig.3.4: Variation in rainfall during crop growing season at Anantapur

3.2.4 Thermal regime at Anantapur

The variations in weekly mean temperature during the cropping season from 29-46 MSW is shown in Fig 3.5a along with the variations in mean seasonal temperature for the years 1971-2010 in Fig 3.5b. The mean weekly temperature remains high (above 28°C) during the sowing, germination and seedling establishment stages. Thereafter the mean weekly temperature remains around 28°C up to 36 MSW coinciding with first flush of flowering and peg penetration phases. During the pod formation stage, the mean weekly temperature is usually between 27 to 28°C and thereafter the temperature starts declining abruptly. This decline coincides with pod development and maturity stages.

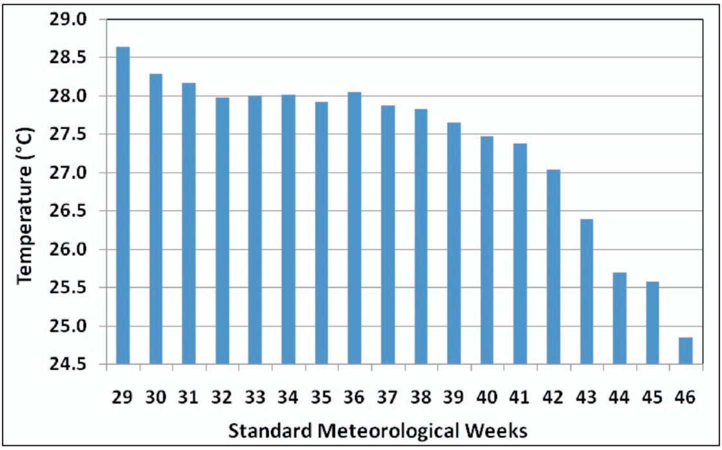

Fig.3.5a: Weekly mean temperature during crop growing season at Anantapur

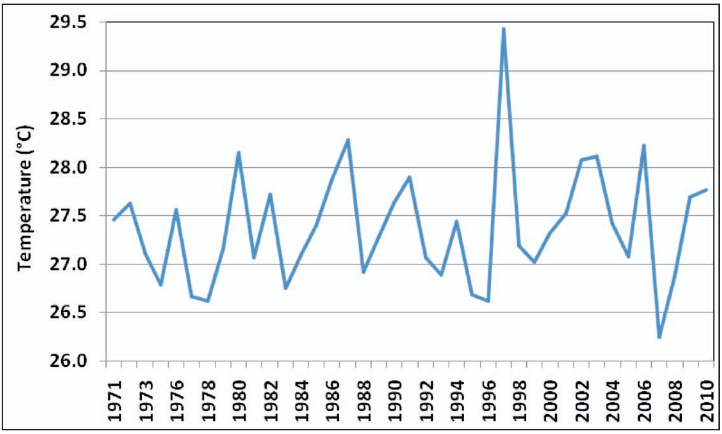

Fig.3.5b: Variations in mean seasonal temperature at Anantapur (1971 -2010)

The mean seasonal temperature was considered in four groups:

Group I	:	26.1 to 27.0°C
Group II	:	27.1 to 28.0°C
Group III	:	28.1 to 29.0 °C
Group IV	:	>29.0 °C

3.2.5 Maximum temperature during growing season

The mean weekly maximum temperature from 29-46 MSW along with mean seasonal maximum temperature for the years 1971-2010 are shown in Fig 3.6a and 3.6b, respectively. The mean weekly maximum temperature remains above 33°C during the sowing, emergence and establishment phases. Subsequently the mean weekly maximum temperature varies between 32 to 33°C up to 42 MSW by which time the crop completes its pod development and enters physiological maturity. During the ripening and harvesting period, the mean maximum temperature ranges between 31 to 32°C. The mean seasonal maximum temperature during the cropping season was found to vary between 31.1 to 33.8°C.

Maximum temperature is classified in to three groups.

Group I	:	31.1 – 32.0°C
Group II	:	32.1 – 33.0°C
Group III	:	>33.0°C

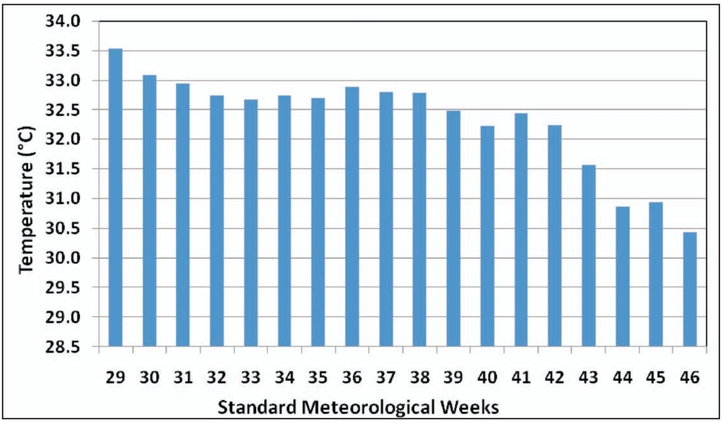

Fig.3.6a: Weekly maximum temperature during crop growing season at Anantapur

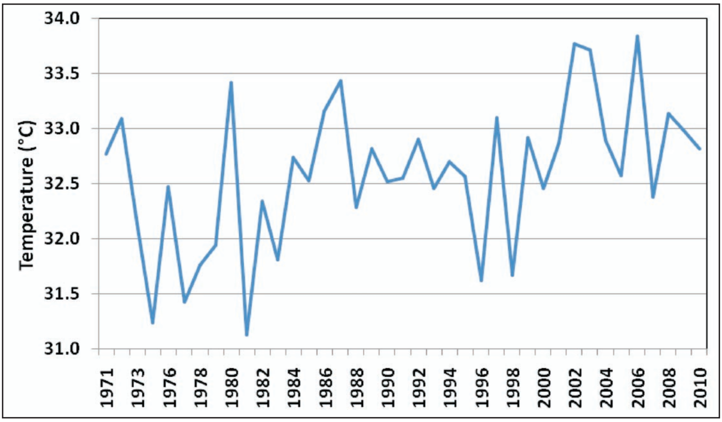

Fig.3.6b: Variations in weekly maximum temperature at Anantapur (1971 -2010)

3.2.6 Minimum temperature during growing season

The mean weekly minimum temperature for 29-46 MSW period during the cropping season is shown in Fig 3.7a. The mean weekly minimum temperature continues to be greater than 23°C up to 36 MSW which coincides with the seeding to pod penetration period. Thereafter the minimum temperature varies between 22°C to 23°C up to 41 MSW and starts declining rapidly, thereafter. The mean seasonal minimum temperature was found to vary mostly between 21°C to 23.5°C (Fig 3.7b). Thus, the thermal regime based on seasonal minimum temperature was arranged in three groups.

Group I	:	21.1 to 22.0°C
Group II	:	22.1 to 23.0°C
Group III	:	>23.0 °C

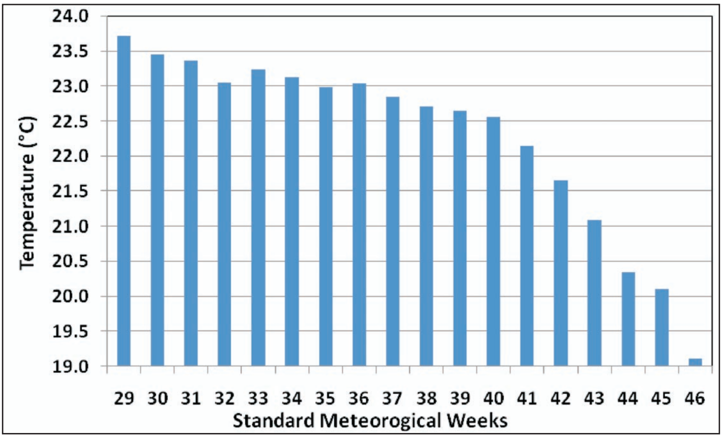

Fig.3.7a: Weekly minimum temperature during crop growing season at Anantapur

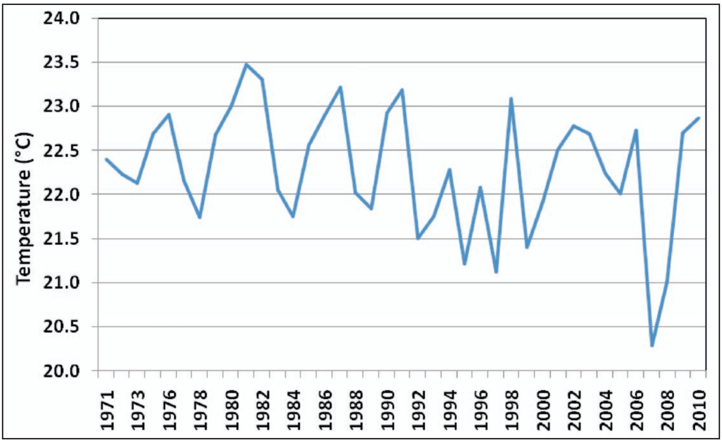

Fig.3.7b: Variations in weekly minimum temperature at Anantapur (1971 -2010)

3.2.7 Diurnal temperature range during crop season

The average diurnal range in temperature during 29 to 46 MSW is shown in Fig 3.8a. The diurnal range in temperature was found to be more than 9.5°C during 29th to 31st MSW. In between the period from 32 to 40 MSW, the diurnal range in temperature was found to vary mostly from 9.0 to 10.0°C. Therefore, the diurnal range in temperature was more or less uniform from the crop establishment to pod filling period. The mean seasonal diurnal temperature range during the cropping season for the years 1971-2010 is shown in Fig 3.8b. The range in temperature during the cropping season varied between

7.5 °C to 11.8°C from season to season. Therefore, the temperature range was considered in the following three groups:

Group I	:	<9.5°C
Group II	:	9.5 – 10.5°C
Group III	:	> 10.5°C

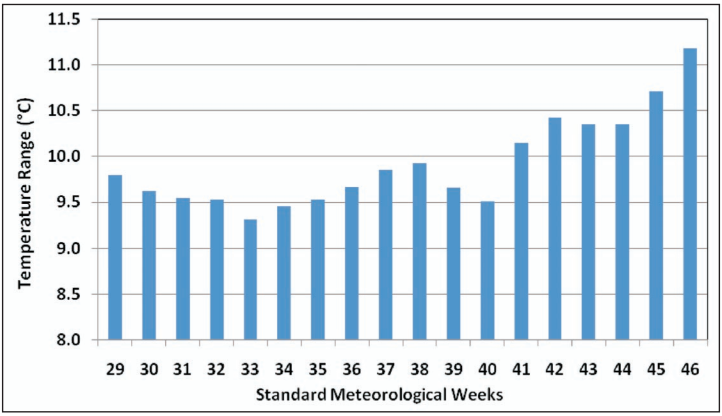

Fig 3.8a: Weekly temperature range during crop growing season at Anantapur (1971-2010)

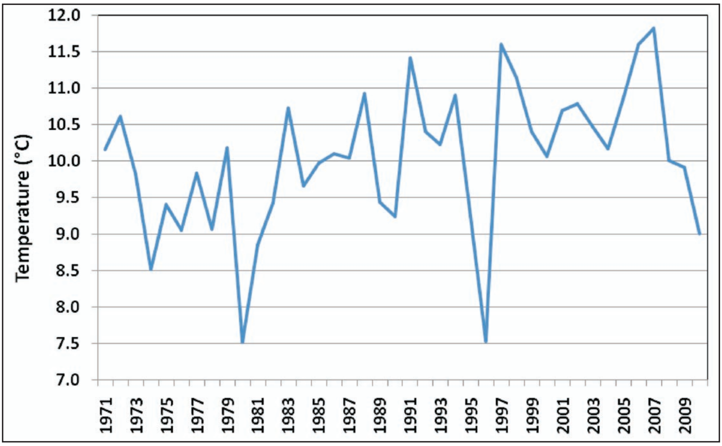

Fig 3.8b: Variation in temperature range at Anantapur (1971-2010)

3.3 Groundnut yields at Anantapur

The experimental pod yield of groundnut for the years 1985-2010 is shown in Fig 3.9. The average pod yield was observed to be 1075 Kg/ha and is varying between little over 200 kg/ha to 2000 kg/ha from year to year.

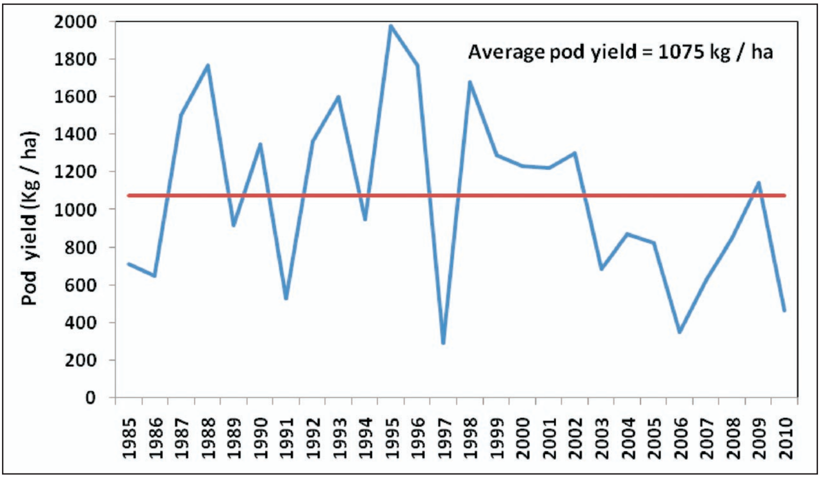

Fig 3.9: Variation in pod yield of groundnut at Anantapur

4. THERMAL, MOISTURE REGIMES AND CROP PRODUCTIVITY

The United Nations Conference on Desertification (UNESCO, 1977) defined bio-climatic zones based on the climatic aridity index (Im) taking in to account atmospheric humidity, wind and solar radiation for determining PET. The zonation helps in understanding the type of climate to which a crop is exposed. The groundnut crop at Anantapur district experiences mostly arid conditions that occasionally move towards semi-arid. The analysis on the impact of moisture and thermal regimes on groundnut productivity in Anantapur district is presented in Table 4.1. It can be inferred from the table that as the water availability to the crop improves by moving from arid to semi arid conditions and with decline in mean temperature by 0.6°C the yield increased by 7.7 per cent.

The influence of seasonal rainfall variability alone on the district-wise groundnut yields are presented in Table 4.2. It is evident from the table that in the years when the seasonal rainfall was 10 per cent less than the normal the yields were reduced drastically by 42 per cent. However, during the excess rainfall years also the yields decreased may be due to the failure on the part of the farmers to capitalize on the good rainfall and not adopting proper technology and management practices to reap good yields. The extension agencies may have to look into this problem.

The analysis on the impact of moisture and thermal regimes on groundnut productivity at Anantapur (Yield and weather data at ARS, Anantapur) is presented in Table 4.3. The groundnut crop at Anantapur station experiences mostly arid conditions and occasionally semi-arid

Table 4.1: Climate variability, thermal regime during cropping season and groundnut productivity in Anantapur District (1972 – 2008)

Climate type	Moisture Index (%)	Seasonal temperature (°C)				Average yield (kg/ha)	Per cent increase in yield
		Max.	Min.	Mean	Diurnal range		
Arid	-76.0	32.8	22.7	27.7	10.2	670.0	-
Semi-arid	-62.2	32.1	22.1	27.1	10.0	726.0	7.7

Table 4.2: Effect of seasonal rainfall variability on average district yield of groundnut in Anantapur district

Scenario	Average yield of groundnut (kg/ha)	Per cent change in yield with respect to normal season
Decrease in seasonal rainfall by 10 per cent or more	498	- 42.0
Seasonal rainfall in the range of ±10 per cent deviation from normal	858	0.0
Seasonal rainfall in excess of more than 10 per cent above normal	772	-10.0

Table 4.3: Climate variability, thermal regime during cropping season and groundnut productivity at Anantapur (1985 – 2010)

Climate type	Moisture Index (%)	Seasonal temperature (° C)				Average yield (kg/ha)	Per cent increase in yield
		Max.	Min.	Mean	Diurnal range		
Arid	-77.5	32.8	22.7	27.7	10.2	957.0	-
Semi-arid	-59.0	32.1	22.1	27.1	10.0	1297.0	26.2

as in the case of Anantapur district. It can be inferred from the table that whenever climate is moving from arid to semi arid conditions the groundnut yields were increased by 26.2 per cent.

To determine the effect of rainfall variability on productivity of groundnut irrespective of the thermal regime, the individual years were grouped as

- Seasons with decrease in rainfall by more than 10 per cent from the normal
- Seasons with rainfall ±10 per cent deviation from normal and
- Seasons with increase in rainfall by 10 per cent from normal

The average productivity of groundnut under the three rainfall regimes considered is given in Table 4.4. It is observed that the productivity groundnut increases with increase in rainfall. During the seasons with normal rainfall, the average productivity was observed to be 1177 kg/ha whereas the deficit in rainfall by more than 10 per cent during the season resulted in reduction in the yield by 23.1 per cent. However, the increase in seasonal rainfall by more than 10 per cent above the normal resulted in increase of average yield by 9.3 per cent only.

Table 4.4 : Effect of rainfall variability on average yield of groundnut irrespective of thermal regime

Scenario	Average yield of groundnut (kg/ha)	Per cent change in yield with respect to normal season
Decrease in seasonal rainfall by 10 per cent or more	905	-23.1
Seasonal rainfall in the range of ±10 per cent deviation from normal	1177	0.0
Seasonal rainfall in excess of more than 10 per cent above normal	1286	+9.3

The effect of maximum temperature during the season on the average groundnut productivity irrespective of the rainfall regime is shown in Table 4.5. The average yield during the seasons with maximum temperature between 31.0 – 32.0°C is observed to be 1306

Table 4.5: Effect of seasonal maximum temperature on average yield of groundnut irrespective of rainfall regimes

Mean seasonal maximum temperature (°C)	Average yield of groundnut (kg/ha)	Per cent decrease in yield due to increase in temperature
31 - 32	1306	—
32 - 33	1023	21.7
>33	960	26.5

kg/ha compared to 1023 kg/ha with average seasonal maximum temperature between 32-33°C. During the seasons with maximum temperature over 33°C, the average productivity was only 960 kg/ha. The percentage decrease in average yield of groundnut was observed to be 21.7 and 26.5 per cent for rise in temperature by 1°C and 2°C, respectively, there by indicating the detrimental effect of rise in maximum temperature on groundnut yield in general.

The average seasonal minimum temperature was mostly observed to be more than 22°C and in few seasons it was between 21 and 22°C.

The average productivity of groundnut during the seasons with minimum temperature less than 22°C and more than 22°C is shown in Table 4.6. It can be seen that the increase in seasonal minimum temperature beyond 22°C resulted in decline in average productivity by 26.2 per cent.

Table 4.6: Effect of seasonal minimum temperature on average yield of groundnut irrespective of rainfall regimes

Mean seasonal maximum temperature (°C)	Average yield of groundnut (kg/ha)	Per cent decrease in yield due to increase in temperature
<22.0	1417	—
>22.0	1056	26.2

The effect of mean daily temperature during the growing season on average productivity of groundnut irrespective of rainfall regimes is shown in Table 4.7. The average productivity of groundnut during the seasons with mean temperature <27.0°C was observed to be 1366 kg/ha. During the seasons with mean temperature between 27-28°C, the average yields were 1048 kg/ha resulting in decline in yield by 23.3 per cent. However, during the seasons with mean temperature >28°C, the average productivity was 827 kg/ha thereby showing a decline in productivity by 39.5 per cent. So the yields of groundnut have shown a decreasing tendency with increase in maximum temperature, minimum temperature and as well as with mean daily temperature during the growing season.

Table 4.7: Effect of seasonal mean temperature on average yield of groundnut irrespective of rainfall regimes

Seasonal mean daily temperature (°C)	Average yield of groundnut (kg/ha)	Per cent decrease in in yield due to increase in temperature
<27.0	1366	—
27.0 – 28.0	1048	23.3
>28.0	827	39.5

The average productivity of groundnut in relation to the mean diurnal range of temperature during the season is presented in Table 4.8. There was not much significant difference in yields when the diurnal range is considered without taking into account the variation in the rainfall regimes.

Table 4.8: Effect of seasonal diurnal temperature range on average yield of groundnut irrespective of rainfall regimes

Growing season mean diurnal temperature range (°C)	Average yield of groundnut (kg/ha)
<9.5	1015
9.5 – 10.5	1082
>10.5	1076

In order to examine the interactive effect of temperature and rainfall variability on the productivity of groundnut at Anantapur the scenarios have been organized as given in Table 4.9.

Table 4.9: Scenarios identified to assess the interactive effect of temperature and rainfall variability on productivity of groundnut at Anantapur

Rainfall variability	Thermal regimes during growing season	Group I	Group-II	Group-III	Group-IV
Seasonal rainfall more than 477 mm	Mean Temperature	26.1 -27.0	27.1-28.0	28.1-29.0	>29.0
	Maximum Temperature	31.1-32.0	32.1-33.0	>33.0	—
	Minimum Temperature	21.1-22.0	22.1-23.0	>23.0	—
	Average diurnal range in temperature	<9.5	9.5-10.5	>10.5	—
Seasonal rainfall between 319 and 477 mm	Mean Temperature	26.1 -27.0	27.1-28.0	28.1-29.0	>29.0
	Maximum Temperature	31.1-32.0	32.1-33.0	>33.0	—
	Minimum Temperature	21.1-22.0	22.1-23.0	>23.0	—
	Average diurnal range in temperature	<9.5	9.5-10.5	>10.5	—
Seasonal rainfall less than 319 mm	Mean Temperature	26.1 -27.0	27.1-28.0	28.1-29.0	>29.0
	Maximum Temperature	31.1-32.0	32.1-33.0	>33.0	—
	Minimum Temperature	21.1-22.0	22.1-23.0	>23.0	—
	Average diurnal range in temperature	<9.5	9.5-10.5	>10.5	—

4.1 Average daily temperature during crop season and productivity

The pod yields were grouped for the seasons under different scenarios for the years 1985-2010. And in each case the average yield and the maximum yields obtained under different scenarios were identified. The effect of mean daily temperature during growing season under three variable rainfall situations considered is shown in Fig 4.1. It is observed that the mean daily temperatures were more than 27°C during the seasons with deficit and low rainfall (319 mm or less). The

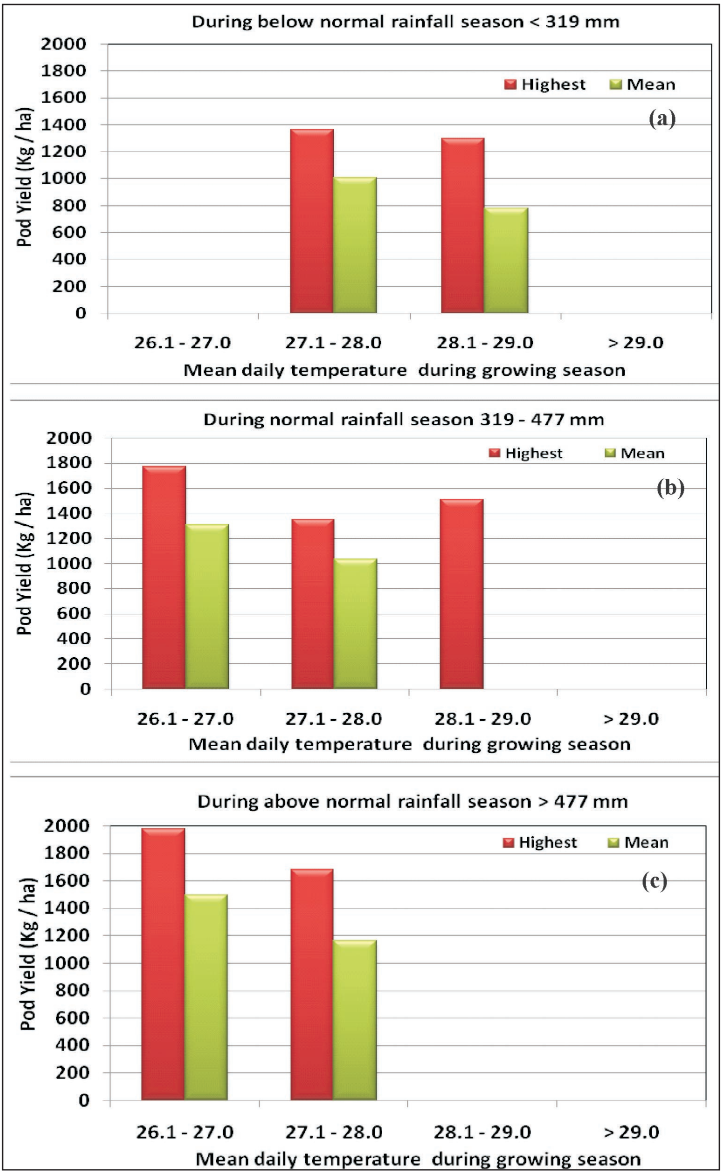

Fig 4.1: Interactive effects of mean daily temperature and seasonal rainfall on the pod yield of groundnut at Anantapur

decline in average yield with increase in temperature in dry seasons was appreciable and 1°C rise in temperature resulted in decrease in average productivity by 2 q/ha where as maximum productivity decreased by about 80 kg/ha per 1°C rise in seasonal temperature. Therefore increase in seasonal temperature will definitely have an adverse impact on the productivity of groundnut during the years with very low rainfall.

During the years with rainfall ranging from 319 - 477 mm also, the increase in temperature has contributed to decline in productivity to the extent of more than 250 kg/ha per 1°C rise in temperature.

During the seasons with rainfall more than 477 mm, the mean daily temperature during the growing season remained below 28°C. However, the increase in temperature by 1°C had adverse impact on maximum yield as well as average yield. The average yield declined by almost 300 kg/ha per 1°C increase in temperature even during seasons with above normal rainfall. It is very evident under Anantapur conditions that the increase in mean daily temperature by 1°C during the crop season will adversely affect the groundnut yields by 200 to 350 kg/ha, irrespective of the rainfall regime.

4.2 Maximum temperature

The effect of daily maximum temperature during growing season on the yield of groundnut in different rainfall regimes are shown in Fig 4.2. During the seasons with rainfall less than 319 mm, the maximum temperature remained above 32°C and the increase in maximum temperature by 1°C resulted in decline in average productivity by 150 kg/ha. However, during the seasons with rainfall between 319 -477 mm the maximum temperature appears to have remained between 32 to 33°C with only one individual case beyond the limits and therefore there was no opportunity for comparison. But during the seasons with rainfall above 477 mm, the daily maximum temperature remained below 33°C only. However, the increase in maximum temperature by 1°C has shown decline in average productivity by 500 kg/ha even during the good rainfall years, although the maximum productivity was better when the maximum temperature was between 32-33°C. Thus, it is obvious that the increase in maximum temperature is also likely to have adverse impact on average yields.

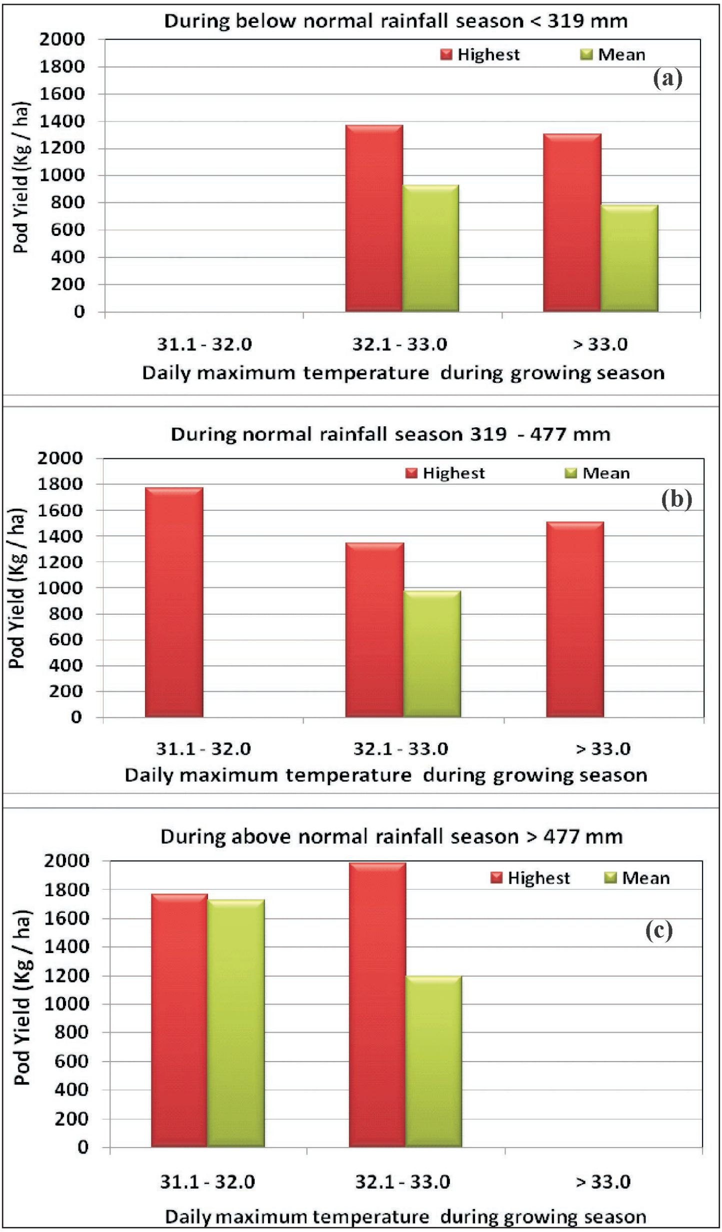

Fig 4.2: Interactive effects of daily maximum temperature and seasonal rainfall on the pod yield of groundnut at Anantapur

4.3 Minimum Temperature

The effect of minimum temperature on the productivity of groundnut under different rainfall scenarios is shown in Fig 4.3. The effect of increase in minimum temperature was more prominent during the dry seasons with seasonal rainfall less than 319 mm. And the

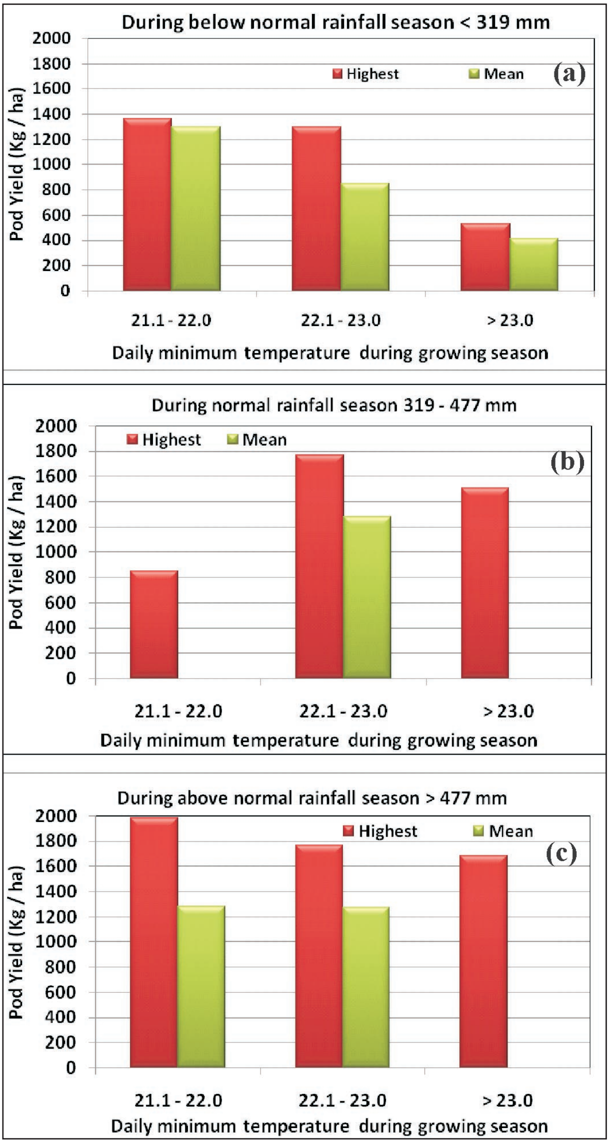

Fig 4.3: Interactive effects of daily minimum temperature and seasonal rainfall on the pod yield of groundnut at Anantapur

increase in minimum temperature by about 1 and 2°C resulted in decrease in average productivity by more than 400 and 800 kg/ha, respectively. Thus it is obvious that increase in minimum temperature will definitely have adverse effect on the productivity of groundnut during dry years with seasonal rainfall <319 mm. However, the increase in minimum temperature appears to have no significant impact on the productivity of groundnut during good rainfall seasons with seasonal rainfall greater than 477 mm.

4.4 Diurnal temperature range during crop season

The effect of mean daily range of temperature during the growing season under different rainfall scenarios is shown in Fig 4.4. The increase diurnal range in temperature has shown marked decline in productivity in all the three rainfall scenarios considered. During break monsoon conditions the skies are likely to be clearer and cloud free. Under clear sky conditions, the nocturnal terrestrial radiation will be more thereby the diurnal range in temperature tends to increase. Thus the increase in diurnal range in temperature by 1°C was found to decrease the productivity of groundnut by more than 300 kg/ha during the years with seasonal rainfall less than 477 mm.

However, during good rainfall years with seasonal rainfall more than 487mm the increase in diurnal range in temperature by 1°C was found to cause decline in productivity by 200 kg/ha. Therefore, it is obvious that under arid conditions of Anantapur, the variability in temperature has very adverse effect on the productivity of groundnut. The yields are likely to decline even with increase in temperature or even with increase in diurnal range temperature irrespective of the rainfall regimes. This indicates that research efforts have to be more focused in identifying the practices that are comparatively less sensitive to variability in temperature. The choice may be identification of groundnut varieties comparatively less sensitive to changes in temperature and moisture and water conservation and mulching practices that can mitigate the impact of increase in temperature and ensure better moisture availability to the crop.

With declining average yields the overall profitability of groundnut production is expected to decline. Crop diversification with less water intensive crops like soybean and pulses need to be promoted. Though groundnut crop is well suited for arid conditions of Anantapur district,

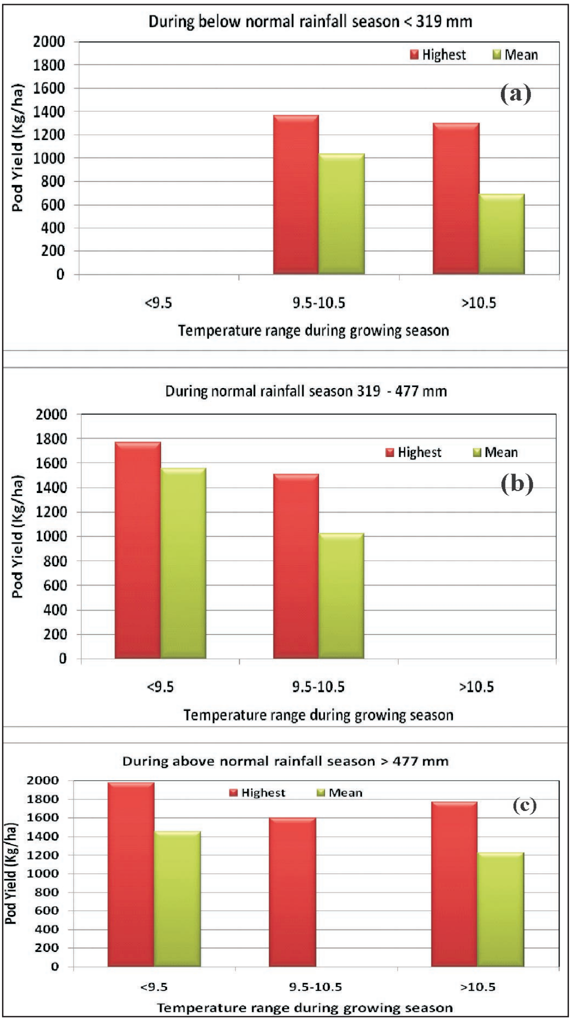

Fig 4.4: Interactive effects of daily temperature range and seasonal rainfall on the pod yield of groundnut at Anantapur

increased mono-cropping and absence of diversification can increase crop vulnerability to pest and diseases, undependable rainfall as well as market price fluctuations. Drought adaptation measures like increasing water-use efficiency by the use of drips, sprinklers and water harvesting measures need to be encouraged. The performance of different practices may not have uniform effect on the productivity under variable thermal regimes. Therefore, a critical analysis on the performance of moisture conservation practices has to be carried out.

5. SUMMARY

There is growing interest worldwide to monitor the impact of global climate change on agricultural production potentials as well as on crop productivity. Hitherto most of the studies are based on simulating crop yields incorporating changes in temperature and carbon dioxide levels with the help of crop growth models. However, no methodology is available to understand the interactive effects of thermal and moisture regimes on crop productivity particularly in tropical drylands using real time data.

Therefore, an explorative study was undertaken to examine the possibility of assessing the impact of increase in temperature and moisture regimes on crop productivity in dryland ecosystem. For this purpose, the productivity of groundnut recorded at Agricultural Research Station, Anantapur during the years 1985-2010 grown under rainfed conditions was utilized.

The individual effects of rainfall regime and thermal regime on groundnut productivity were examined considering different scenarios. The crop productivity was found to increase from deficit seasonal rainfall scenario to good rainfall scenario. There was a decrease in productivity with increase in seasonal mean, maximum and minimum temperatures irrespective of the moisture regime.

The climatic scenarios can be organized by grouping different combinations of thermal and moisture regimes. The average as well as maximum productivity of the crop with various climatic scenarios was examined. In case of the area considered, it was very clear that increase in temperature has profound influence on productivity during deficit rainfall years. During the seasons with seasonal rainfall less than 319 mm, the seasonal maximum temperature remained above 32°C and the increase in seasonal maximum temperature by 1°C resulted in decline in average productivity by 150 kg/ha. But during the seasons with rainfall above 477 mm, increase in maximum temperature by 1°C has resulted in decline of average productivity by 500 kg/ha. During dry seasons, an increase in minimum temperature by 1 and 2°C resulted in decrease of average productivity by 400 and 800 kg/ha, respectively.

In the study area, the crop productivity appeared to be more influenced by thermal regime compared to moisture regime. In order to address the problems arising out of increase in temperatures over the study area, it is necessary to identify:

- crop and soil management practices to harness the water in excess rainfall seasons,
- varieties less sensitive to changes in thermal regime,
- cultural and management practices that reduce canopy temperature during the seasons with higher air temperatures and
- strategies for reducing the warming effect over the area by improving vegetative cover and creating sink for greenhouse gases.

The analytical approach proposed the present investigation can be extended to various crops and agro-climatic zones to understand the climate change effects on crop productivity in dryland ecosystems in particular and irrigated ecosystems as well.

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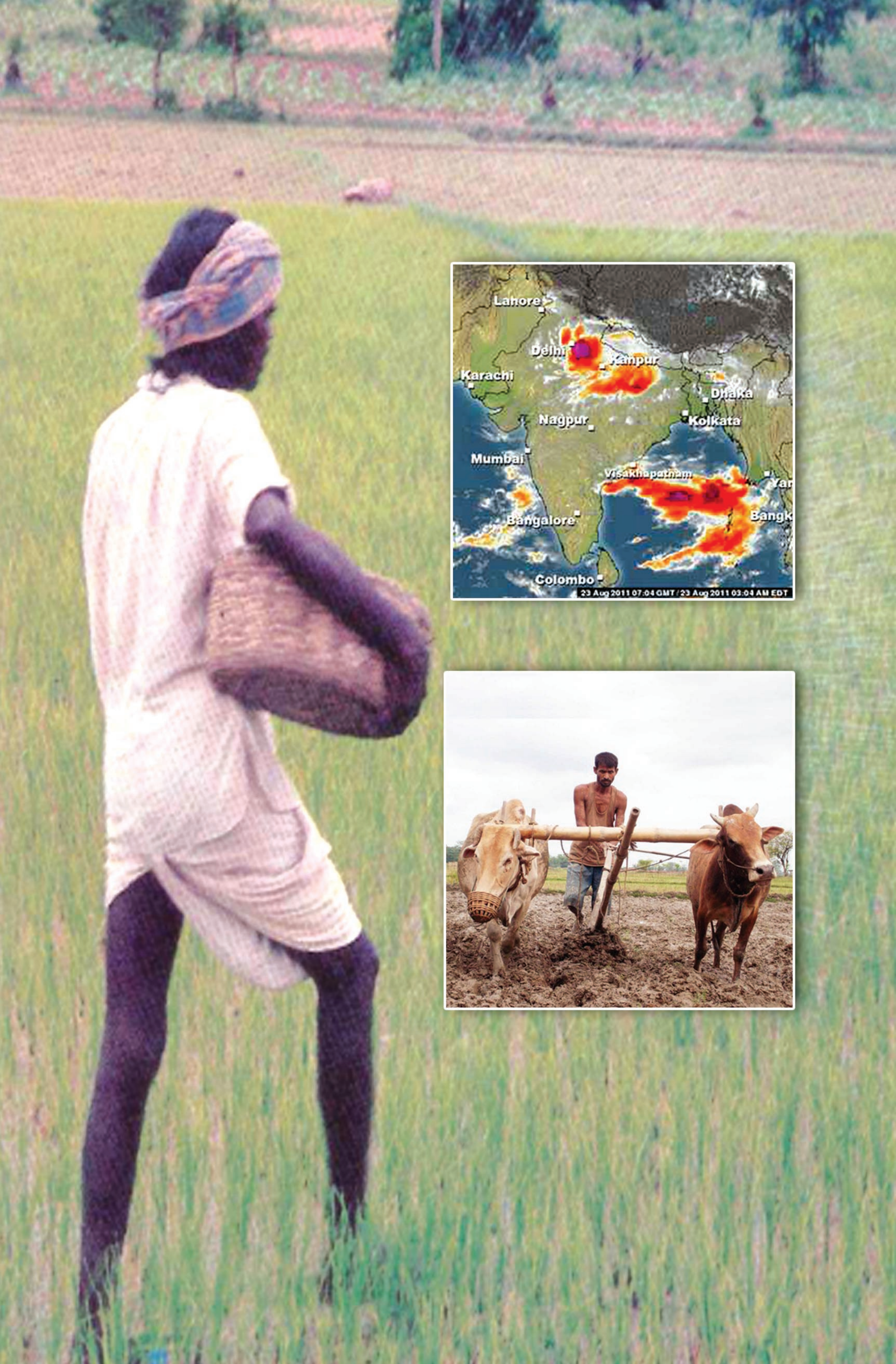

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