Agrometeorology of Rabi Sorghum of North Karnataka

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AICRP on Agrometeorology, Bijapur Centre
November, 2014
Regional Agricultural Research Station, Bijapur
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Dr. D. P. Biradar
Vice-Chancellor

MESSAGE

Agrometeorological analysis for different crops is gaining importance in view of the variable climate and occurrence of repeated extreme weather events during the past two decades. North Karnataka has some of the driest regions in the country and is home for drought hardy crops like pearl millet and sorghum. Notwithstanding the release of new varieties and improved production and protection technologies, the production levels of sorghum that reached up to nine million metric tonnes has been declining in the past decade that can be attributed to multiple complexities. This paradox can be ascribed both to farmers' preference to high value crops resulting in reduction in area and to the influence of frequent adverse weather effect. With the climate change considerations looming large the need for reversing this trend is essential in the traditionally sorghum growing areas, will take care of food security of common man as well as enhance value-added products. To tackle this, understanding the role of weather on growth and yield of *rabi* sorghum gains importance towards our preparedness for the eventualities that may arise due to climate variability and change.

The Technical Bulletin "**Agrometeorology of *rabi* sorghum of north Karnataka**" brought out by AICRP on Agrometeorology, RARS, Bijapur, gains significance in this context. Even though this publication is not all-pervasive, the ideas put forth will help in furthering our research programmes to deal with fluctuations in weather and climate. Untimely and adverse weather conditions have taken their toll on the crop in recent years and identification of suitable management practices for such events is also indeed essential required. Another aspect which needs to be looked into study on weather based crop insurance. Scientists will need to look into various aspects to develop multiple methods and tools including a decision support system that would boost farmers' sustainability against the fluctuating weather.

I am sure this publication will serve as a reference material to different stakeholders – scientists, extension personnel and industry. I extend my hearty congratulations to the authors for their efforts in bringing out this document.

November 1, 2014 **Dr. D. P. Biradar**

Dr. B.M. Khadi
Director of Research

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FOREWORD

Sorghum is grown during the *rabi* season in north Karnataka as rainfed crop under receding soil moisture conditions. The sowing window is almost fixed from September 15^{th} to October end, and the soil moisture situation during primordial initiation stage is considered highly critical for growth and yield of the crop. Meteorological conditions during the remaining part of the season determine adoption of various management practices depending on the stage of the crop. During the past fourteen years, the region has experienced many adverse weather conditions – most of them being extreme. Hence, the need in understanding the role of weather on the crop and its genotypes assumes significance in enhancing productivity. This requirement is met by the Technical Bulletin **"Agrometeorology of *rabi* sorghum of north Karnataka"** prepared by the AICRP on Agrometeorology, Bijapur Centre.

The Bulletin provides information on climate variability in the region, how the farmers opted for different varieties and evolving of new *rabi* sorghum genotypes. More importantly, it provides information on response of the crop to different weather variables during crop growing season and also to extreme weather events. The information on the response of different varieties to the prevailing weather conditions will be useful not only to scientists but also for different stakeholders dealing with sorghum crop. It is also heartening to note that the AICRP on Agrometeorology has worked in tandem with scientists of AICRP on Sorghum at Bijapur while drawing inferences in some of the aspects brought out in the Bulletin, thereby emphasizing the importance and benefits of inter-project collaborations.

Efforts made by the AICRP on Agrometeorology, Bijapur Centre in bringing out this publication are appreciable.

November 1, 2014 **Dr. B.M. Khadi**

PREFACE

The Technical Bulletin **"Agrometeorology of *rabi* sorghum of north Karnataka"** is a compilation of results of the research studies made on weather-influences on growth and development of *rabi* sorghum by Bijapur Centre of AICRP on Agrometeorology and its associate projects.

It is said, climate is what we expect and weather is what we get. In this Bulletin we have presented how variable the climate in north Karnataka was and suggested how to make best use of the available information for choosing appropriate *rabi* sorghum genotypes.

We have presented the association between meteorological variables on one hand and sorghum growth parameters and yield on the other, and also developed yield prediction models. We have dealt with how the different genotypes respond to variations in weather in terms of growth and yield. We have also indicated the utility of crop simulation models in crop phenology and yield predictions at reasonable levels. We took the benefit of extreme events of recent years to evaluate how they impacted *rabi* sorghum yields in north Karnataka.

I take this opportunity to express gratefulness to Dr. D.P. Biradar, Hon'ble Vice Chancellor, UAS Dharwad for providng new ideas in his **Message** for this publication. I am also thankful to Dr. B.M. Khadi, Director of Research, UAS Dharwad for his keen interest in Agrometeorological research and scripting the **Foreword** to this Bulletin in spite of his extremely busy schedule.

Dr. V. Umamaheswara Rao, Project Coordinator, AICRPAM, leads his team of AICRPAM scientists from the front, instills confidence in their work and inspires them to put their best foot forward for the success of the Project. I profusely thank him for arranging to review the draft of this publication and make it more meaningful.

The outcome of research presented herein is due to the efforts by all the co-authors. Soliciting their continued cooperation, I heartily express appreciation to them for their valuable inputs.

I thank Dr. R.A. Balikai, Editor, and his associates at the Publication Centre, UAS Dharwad for arranging printing of the Bulletin at a very short notice.

Finally, I solicit suggestions from the readers for making improvements in our future publications.

November 1, 2014 **H. Venkatesh**

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1. Introduction

Sorghum (*Sorghum bicolor* Linn. Moench), popularly known as *Jowar,* is the major cereal consumed in India after rice and wheat. It accounts for nearly 52% area and 63% production under millets grown over 15.1 million hectares and production of 11.85 million tonnes in India (Hosmani and Chittapur, 1997), which later reduced to 6.32 million hectares and 6.03 million tonnes in 2011-12 (DES, 2012). Majority of the crop (90 % of the total area) is grown under rainfed situation during the *rabi* season and 80% of country's production in the states of Maharashtra, Karnataka and Andhra Pradesh. India is the third largest producer of sorghum in the world with 7.15 million tons produced during 2007 (GOI, 2007). It is the staple food grain in most districts of northern Karnataka. Its stover is important for animal feed and the grain for new value added/processed food products such as popped sorghum, papad, porridge, rava and as an ingredient for umpteen Indian dishes like dosa, khichdi etc a sign of its diversified utilization trends. Even though the crop is robust and versatile, it has faced drawbacks in terms of yield and reduction in acreage. In this context, it is necessary to understand the agrometeorological limitations for improvement in yield and arrest the slide in cultivated area.

Rabi sorghum is grown in northern Karnataka mainly as rainfed crop and to a very little extent under irrigated conditions. It is grown in the districts of Bijapur, Bagalkot, Bellary, Belgaum, Bidar, Dharwad, Gadag, Gulbarga, Haveri, Koppal and Yadgir. In view of crop data availability constraints, representation of acreage and production in this report is made for the undivided districts as existed in 1998. The important *rabi* sorghum growing districts are shown in Fig 1.1.

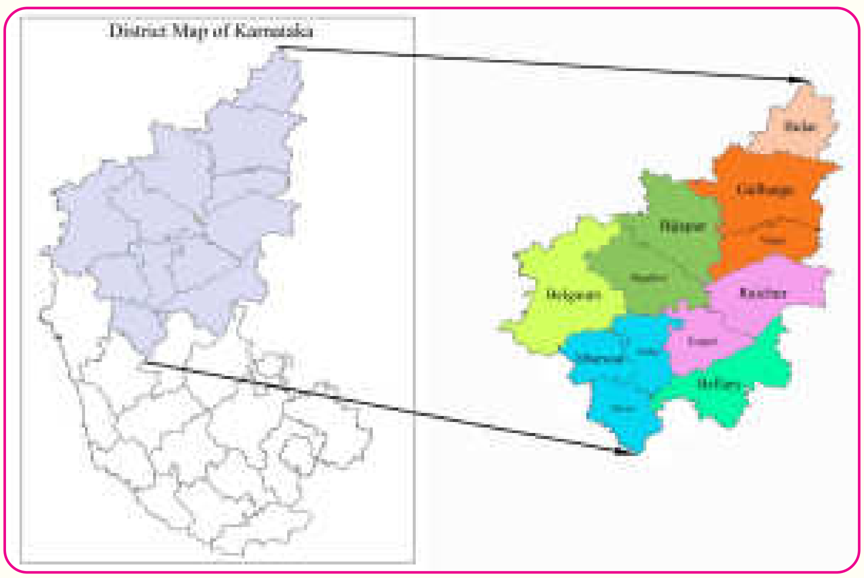
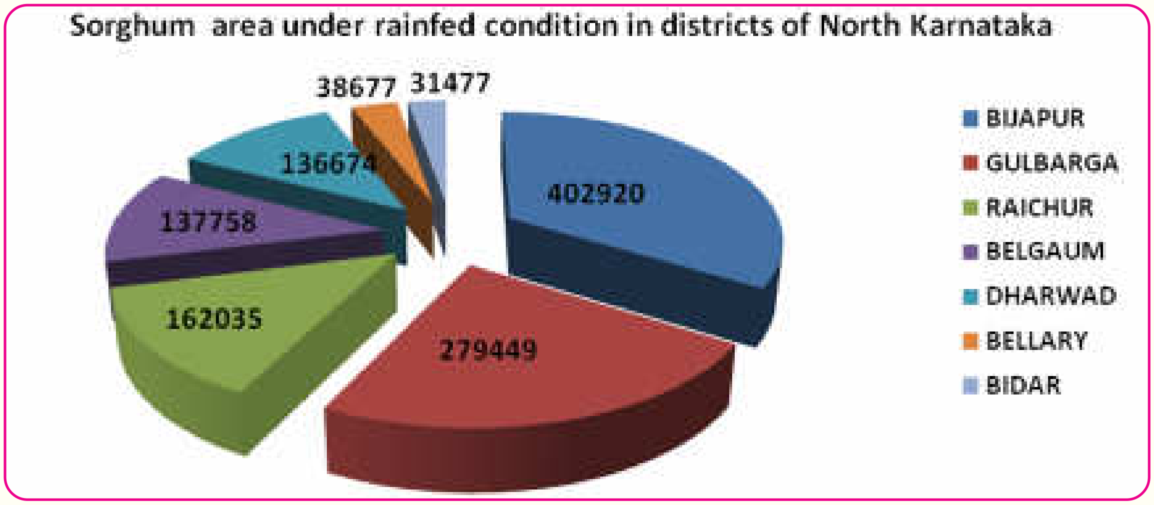


Fig 1.1. *Rabi* sorghum growing districts in northern Karnataka

Area and production of *rabi* sorghum in north Karnataka

The district wise area and production of *rabi* sorghum in north Karnataka are shown in Fig 1.2 and Fig 1.3 respectively. The data are presented as the mean for the period pertaining to 1992-93 to 2009-10. Bijapur district (Bijapur+Bagalkot of today) has the largest growing area of 4.42 lakh ha and also highest production of 3.21 lakh tons.



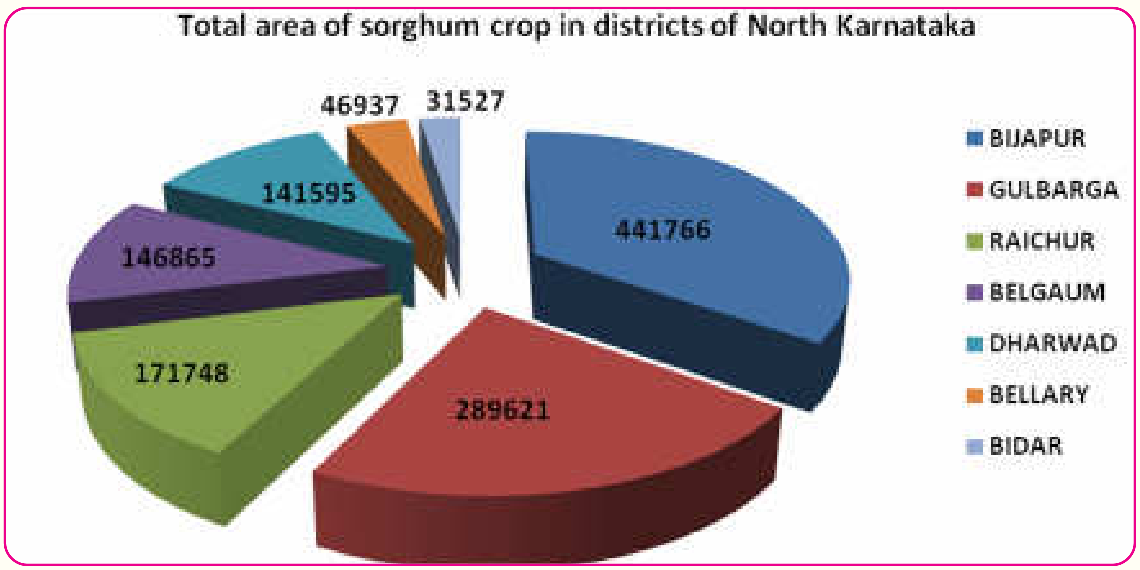
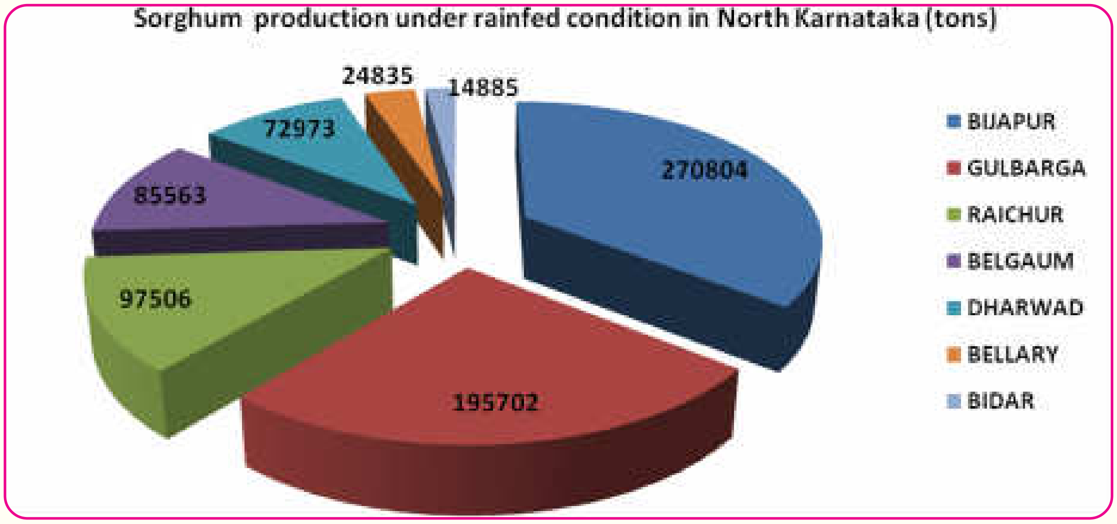


Fig 1.2. District wise area under *rabi* sorghum in North Karnataka (hectares)



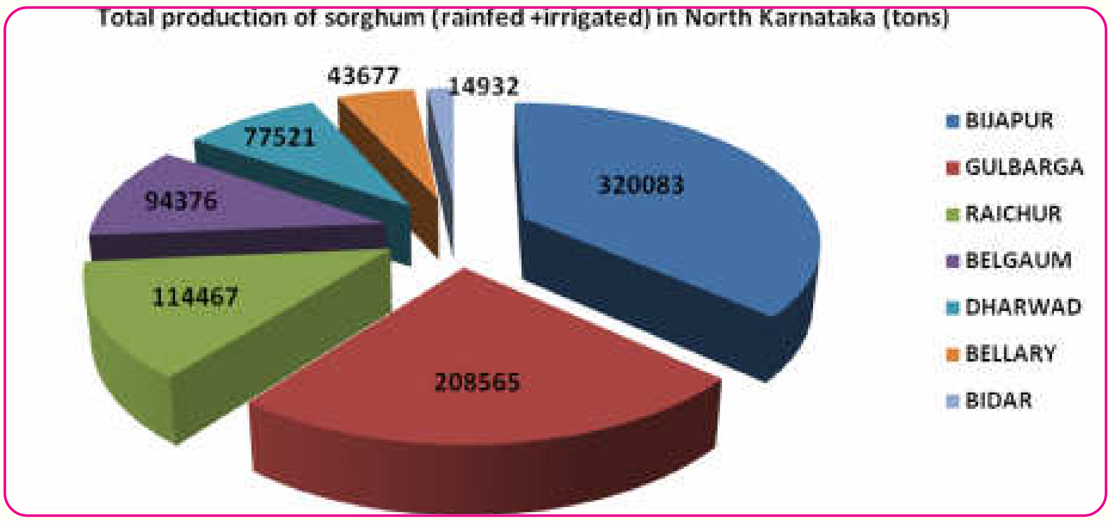


Fig 1.3. District wise production of *rabi* sorghum in North Karnataka (tons)

Trends in area and production

The trends in area and production for the period 1992-93 to 2009-10 are given in Fig 1.4. A general decreasing trend is noticed in both area and production. Area decreased from 16 lakh hectares in 1992-93 to only six lakh hectares in 2009-10, with significant decrease during 2007-2009. On the other hand production decreased from 11 lakh tons during the 1990s to 5.5 lakh tons during 2009-10. In between, sudden decrease in the production was noticed particularly due to extremely low rainfall situations in 1997-98, 2002-03 and 2003-04 seasons. In contrast, irrigated area was more or less constant around 80,000 ha during the period, while the production increased from 90,000 tons to 14 lakh tons. Significant fall in production was noticed in 1998 -99 (high rainfall year) and 2002-03 and 2003-04 (extremely low rainfall years). Thus both high rainfall and low rainfall has adversely affected *rabi* sorghum production.

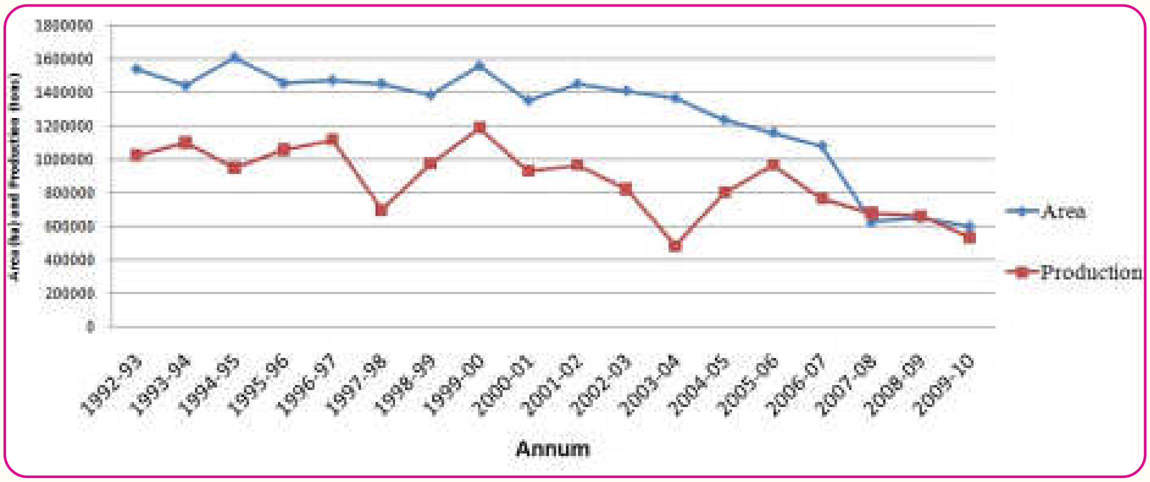


Fig 1.4 Trends in area and production of *rabi* sorghum in North Karnataka (Agregate data)

Sorghum growing conditions

Soils

Soils with clay loam or loam texture having good water retention capacity are best suited for *rabi* sorghum cultivation. It performs well in pH range of 6.0-8.5 as it tolerates considerable salinity and alkalinity. It is grown in medium to deep black soils in northern Karnataka.

Sorghum can be grown successfully in areas with average annual rainfall of 500 to1000 mm. Minimum temperature for the germination is in the range of 7-10 ^{o}C. It needs about 26-30 ^{o}C temperature for its optimum growth. Sorghum is a short day plant. Flowering is hastened by short days and delayed by long days.

Normal cultivation practices for *rabi* sorghum

The sorghum crop is predominantly grown during the *rabi* season in northern Karnataka under receding soil moisture conditions in deep and medium deep soils. The recommended spacing is 60cm x 10cm. Recommended sowing window is from the middle of September to the middle of October. In individual years it is determined not only by the amount and distribution of rainfall during the sowing window, but also by the soil moisture status prior to this window. The crop can grow with even little rainfall later on. The crop duration, growth and yield are determined not only by the rainfall and soil moisture crteria, but also by the other weather variables like temperature, relative humidity and wind direction during the crop growing period.

Phenology of *rabi* sorghum

The information on the various phenological stages of *rabi* sorghum with respect to number of days required for individual stage are given in Table 1.1.

Table 1.1: Phenological development of sorghum crop

Growth stage	Duration (days)
Sowing to germination	6 to 8
Germination to primordial initiation	31to 40
Primordial initiation to flowering	30 to 33
Flowering to maturity	34 to 42
Sowing to primordial initiation	37 to 48
Sowing to flowering	69 to 81
Sowing to maturity	111 to 115

Agrometeorological constraints

Rabi sorghum is grown in north Karnataka under receding soil moisture situation during September – February. Sowing commences from Standard Meteorological Week (SMW) 38 till SMW 41. The crop is not only susceptible to fluctuations in rainfall and soil moisture deficiency during different stages of crop growth, but also to variations in other variables after cessation of rainfall

- Very little rainfall coupled with dry and desiccating winds during winter result in quick depletion of soil moisture
- In some years, absence of rainfall in pre-*rabi* month of August makes the crop growth a failure.
- Intrinsic variability in rainfall patterns of northern Karnataka also result in failure of some genotypes while some others succeed.
- Both higher as well as extremely low minimum temperatures are also constraints for *rabi* sorghum production at the optimum levels.

The research work conducted under AICRP on Agrometeorology has been able to address some of these limitations (Anonymous, 1996-2010) and the same are presented in the ensuing chapters.

2. Characteristics of Crop Growing Environment

Rabi sorghum is generally grown in semi-arid to near-arid conditions of north Karnataka. The district wise normals of rainfall and temperature for the period 1971-2010 are given in Table 2.1. Mean monthly maximum temperature in the crop growing period of September to February is between 29.4 C and 34.2 C, while mean monthly minimum temperature is between 16.5 and 22.4 C. The region also faces dry desiccating north wind during December and January that would affect the crop in some years. September is the month of main rainfall in the region, with normal values varying between 142.1 and 176.8 mm. In the month of October rainfall ranged between 103.1 and 109.4 mm.

Table 2.1: District-normals of temperature and rainfall in north Karnataka (1971-2010)

Month	Bagalkot			Belgaum		
	MaxT (°C)	MinT (°C)	Rainfall (mm)	MaxT (°C)	MinT (°C)	Rainfall (mm)
September	31.05	21.96	142.08	29.36	21.26	145.43
October	31.56	21.39	108.14	30.63	20.77	104.55
November	30.61	18.89	27.51	30.29	18.57	29.87
December	30.01	16.71	6.32	29.87	16.47	4.50
January	31.16	16.88	3.91	30.61	16.20	2.63
February	33.87	18.93	2.69	32.62	17.76	2.61
	Bijapur			Dharwad		
September	31.83	22.24	161.8	29.11	21.11	146.16
October	32.20	21.61	111.79	30.03	20.64	103.10
November	30.85	18.87	23.38	29.81	16.61	31.72
December	30.10	16.63	5.31	29.52	16.64	6.25
January	31.25	17.03	3.79	30.40	16.36	5.75
February	34.17	19.22	2.91	32.42	17.97	4.48
	Gadag			Gulbarga		
September	30.01	21.38	104.30	31.80	22.36	176.84
October	30.50	20.82	103.36	32.05	21.60	108.04
November	29.82	18.63	24.97	30.50	18.85	20.72
December	29.39	16.55	5.21	29.56	16.55	4.72
January	30.60	16.59	1.28	30.58	16.98	4.87
February	33.13	18.57	1.15	33.71	19.36	3.83

	Koppal			Raichur		
September	30.93	21.87	144.30	32.01	21.81	156.52
October	30.98	21.20	107.69	31.80	21.81	109.36
November	29.98	18.87	29.90	30.44	19.35	23.53
December	29.43	16.71	9.47	29.66	17.14	5.93
January	30.70	16.85	3.60	30.79	17.47	3.18
February	33.59	19.07	2.39	33.99	19.77	3.21

Climatic trends and variability

Historical analysis of climate variability

Indian monsoon is noted for its vagaries. Rainfall patterns over India have shown considerable differences in both space and time, suggesting widely varying impacts on the economies of the respective regions (Rupa Kumar, 2002). We present here the 11-year moving averages of rainfall and temperature during the *rabi* sorghum growing season in northern Karnataka for the twentieth century.

Rainfall

Figures 2.1 to 2.4 describe the rainfall variations at 11-year moving average, for September and October for four districts of northern Karnataka. Of the four districts, Bellary and Bijapur correspond to northern dry zone of Karnataka. In Bellary district (Fig.2.1), a clear cyclic nature is found for the September rainfall of three distinct periods centering from 1905-1926, 1927-1956 and 1957-1990. In case of September, the first one was a high rainfall epoch, which followed by a low rainfall epoch and once again by a high rainfall epoch. Thus, the differences between rainfall of September-October were larger in the first and third periods, whereas in the intermediate period the differences were very small.

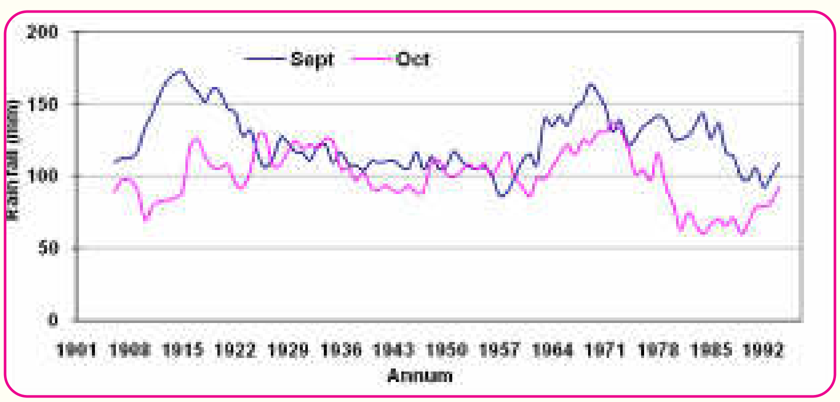


Fig. 2.1 Variability in rainfall during September and October months at Bellary

In contrast to Bellary, slightly positive trend of rainfall was noticed in both September and October at Bijapur (Fig 2.2). Since the 1940s, low rainfall periods of September synchronized with high rainfall periods of October and *vice versa*. The September-October differences were large in high September rainfall epochs. Consequently, in low October rainfall epochs, the *rabi* crops are bound to experience greater terminal moisture stress.

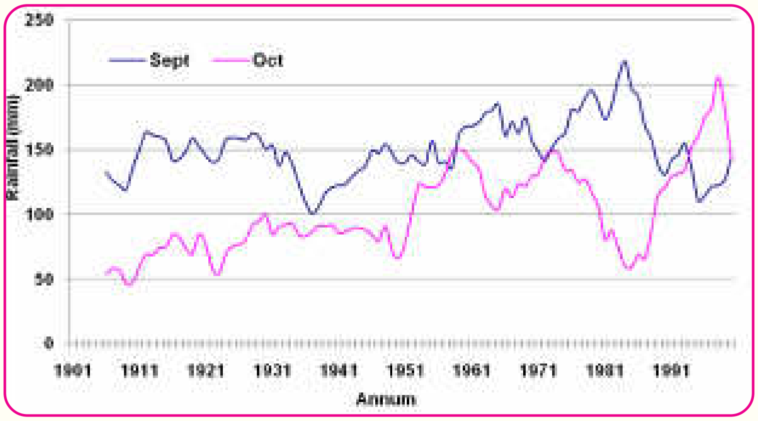


Fig. 2.2 Variability in rainfall during September and October months at Bijapur

Gulbarga and Raichur districts are located in the northeastern dry zone of Karnataka. Of these, in Gulbarga, no linear trend is noticed for September rainfall, whereas the rainfall in October showed a linear trend with increase in 11-year moving averages from about 60mm at the beginning of the 20th Century to 100mm at the end of the Century (Fig 2.3).

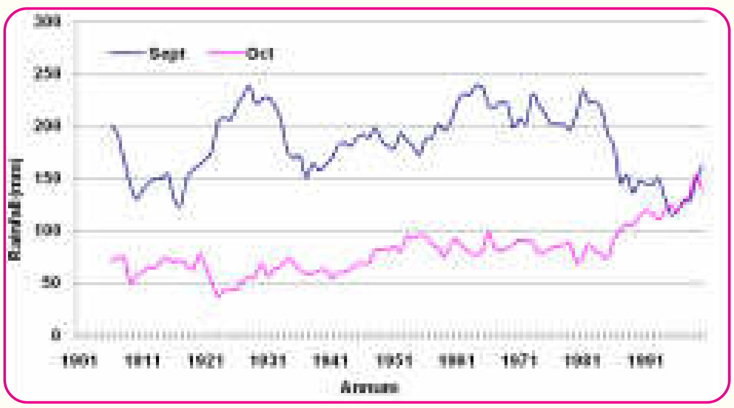


Fig.2.3 Variability in rainfall during September and October months at Gulbarga

A general decrease of rainfall in September and a distinct increase in October were observed during the twentieth Century at Raichur (Fig 2.4). Rainfall profiles were similar for September and October till 1950s. It is from this time that the tendencies became opposite - high rainfall epoch of October synchronizing with low rainfall epoch of September and *vice-versa*. This is similar to Bijapur pattern.

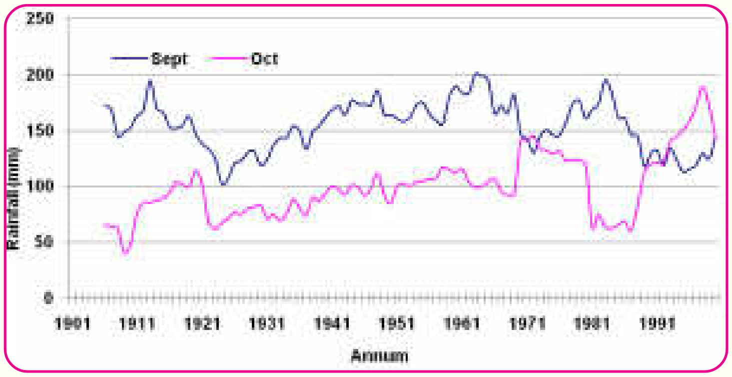


Fig. 2.4 Variability in rainfall during September and October months at Raichur

Temperature

Figures 2.5 to 2.8 present the variability patterns of temperature that prevailed during November and December in four districts. A general decrease of maximum temperature during November and December was noticed at Bellary (Fig 2.5). A low frequency sinusoidal curve could be superposed on the pattern. Similar low frequency sinusoidal nature could be observed for minimum temperature also, but only in the first half of the century. In the second half of the century, maximum temperature showed considerable variability, with alternate high and low epochs. In individual years, maximum temperature varied between 28.0°C and 31.5°C. On the contrary, minimum temperature not only decreased sharply after 1960, considerable interannual variations of more than 6°C were noticed. Rainfall and maximum temperature tendencies were in opposite direction during the high rainfall epochs.

Maximum temperature at Bijapur showed a general increasing trend, but large fluctuations were noticed beyond 1960 (Fig 2.6), resulting in high maximum temperature and low maximum temperature epochs. Minimum temperature variations were very nearly static till about 1950, after which mild low and high minimum temperature epochs prevailed alternately, the sequence being exactly opposite of maximum temperature.

At Gulbarga (Fig.2.7), maximum temperature in both November and December months smoothened out in the later part of the century, indicating nearly stable daytime temperature for crop growth. Minor high and low minimum temperature epochs were noticed.

At Raichur (Fig. 2.8), slightly increasing trend of maximum temperature is noticed in both November and December. Decreasing trend in minimum temperature indicates an increase in diurnal temperature range.

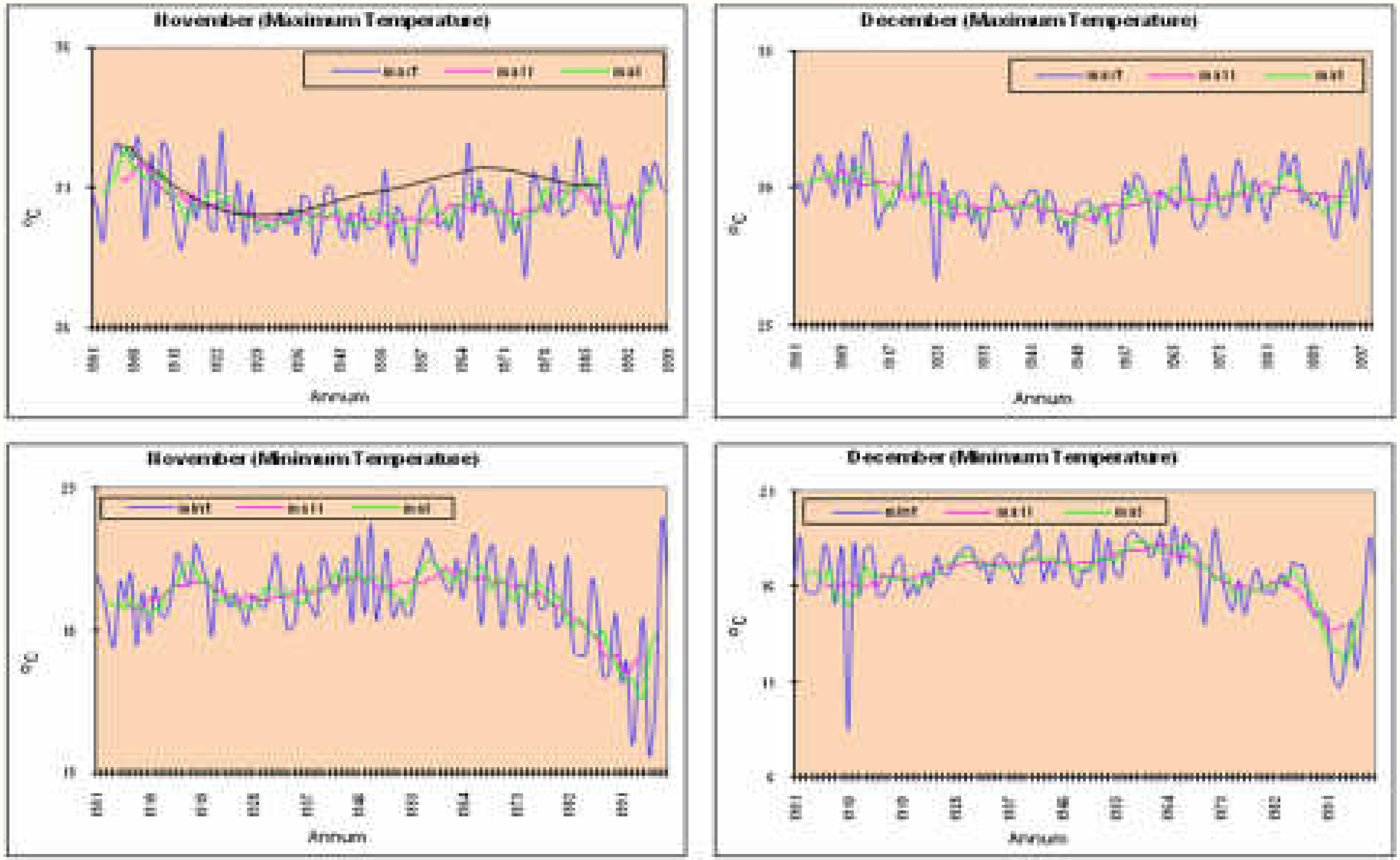


Fig. 2.5 Variability patterns of temperature during *rabi* season at Bellary

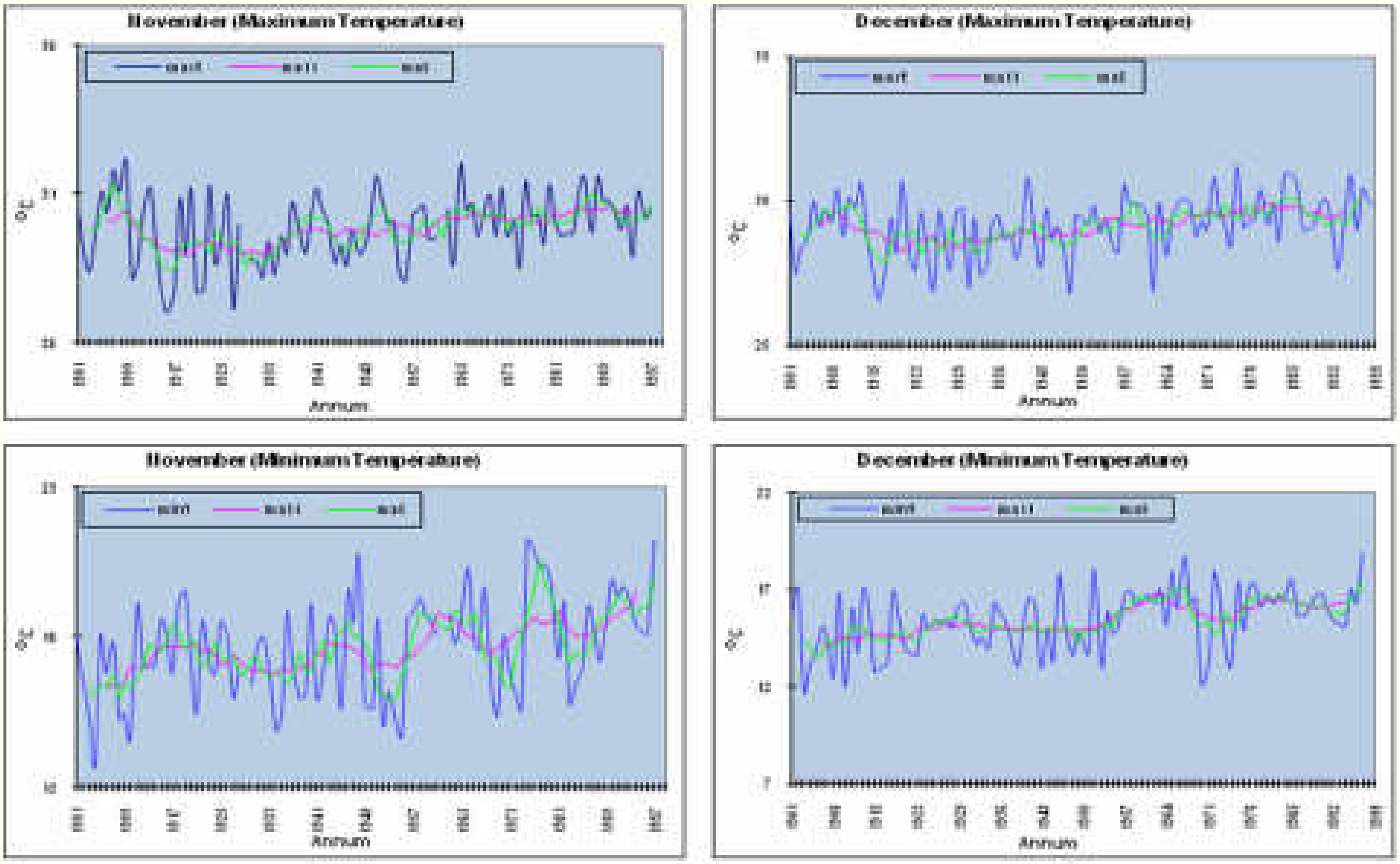


Fig. 2.6 Variability patterns of temperature during *rabi* season at Bijapur

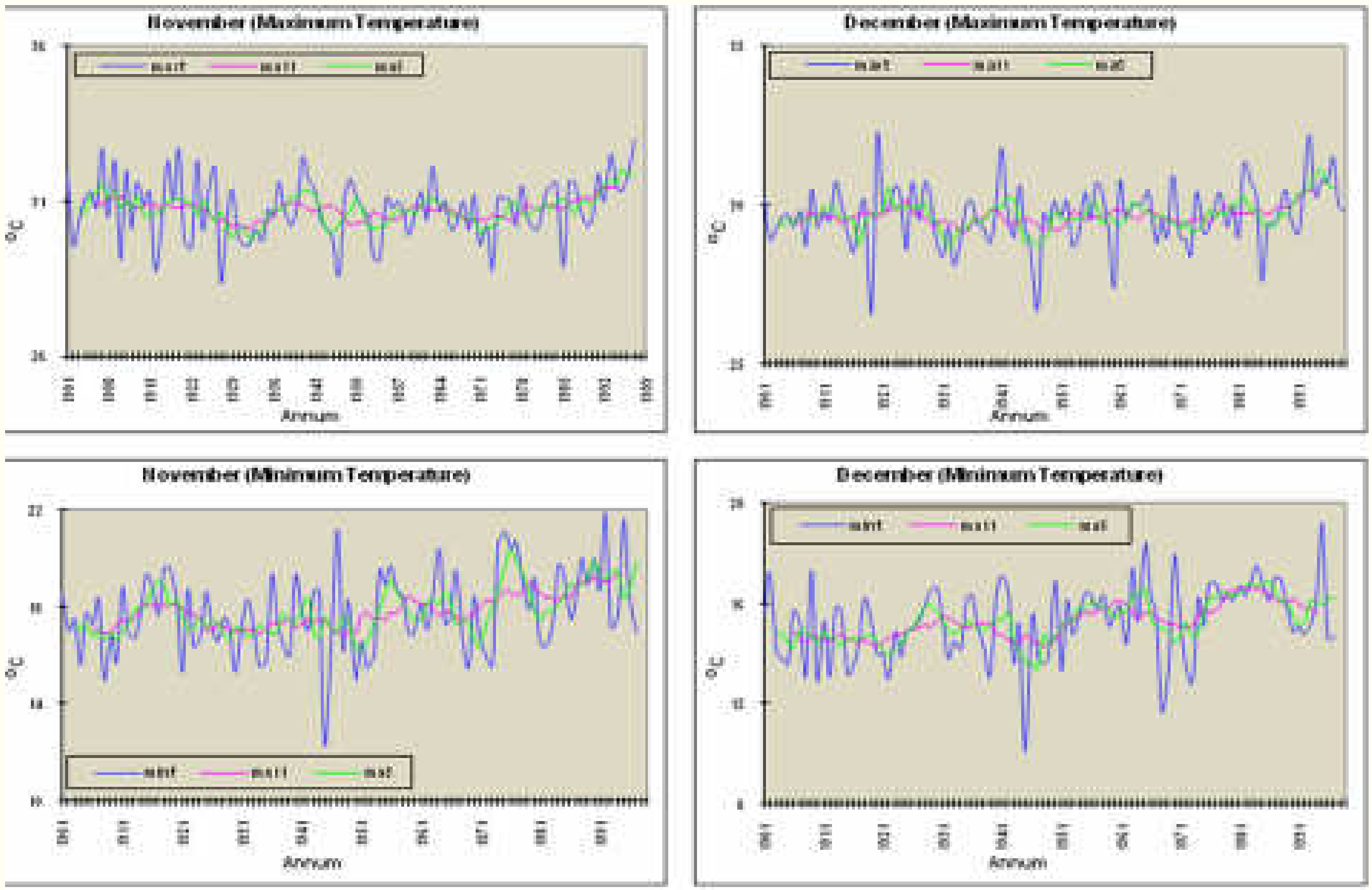


Fig. 2.7 Variability patterns of Temperature during *rabi* season at Gulbarga

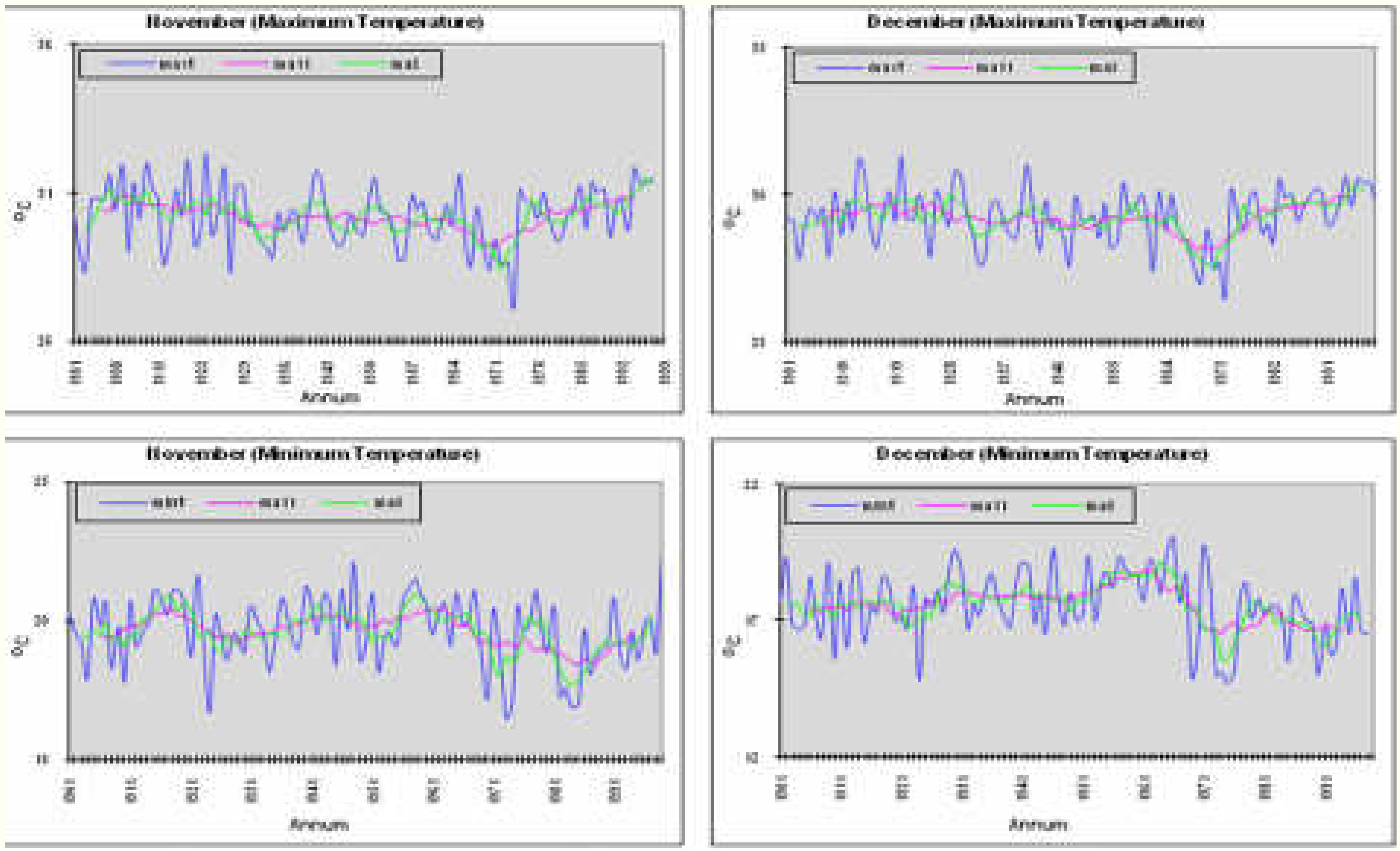


Fig. 2.8 Variability patterns of Temperature during *rabi* season at Raichur

Rainfall variations in the past two decades

Availability of sorghum yield data on a regional scale for the period 1992-2009 only has compelled us to look into variations in rainfall at monthly and seasonal time scales for the corresponding period (Fig 2.9 and Fig 2.10).

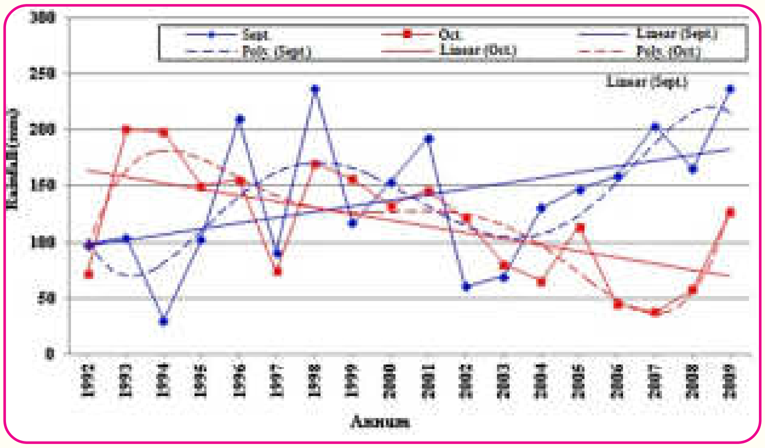


Fig. 2.9 Trends in rainfall of September and October over North Karnataka

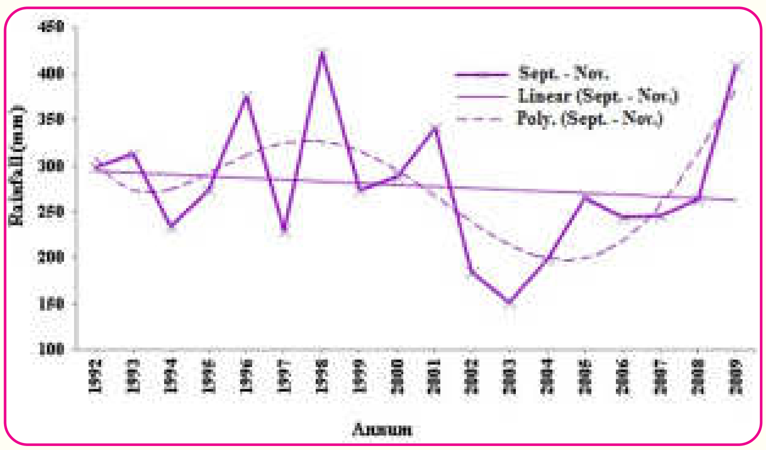


Fig. 2.10 Trends in *rabi* season (September-November) rainfall over North Karnataka

September rainfall (Fig 2.9) showed increasing trend during 1992-2009, while October rainfall showed decreasing linear trend. Seasonal rainfall (Fig 2.10) experienced slightly decreasing trend during the period 1992-2009. It is also noticed that the data had sinusoidal variations in all the three cases (September, October and *rabi* season). The data are best fit at 5th degree polynomial, and the highest R^2 is observed for October rainfall (O.68) as given in Table 2.2. This also reiterates continuity of the cyclic variations that existed in historical data of 20th Century.

Table 2.2 Best fit relations between rainfall and sorghum yields

Month/ Season	Equation	R^2
September	$y = -0.01x^5 + 0.48x^4 - 8.3x^3 + 60.25x^2 - 161.9x + 212.44$	0.48
October	$y = 0.01x^5 - 0.475x^4 + 8.1x^3 - 62.8x^2 + 206.9x - 57.05$	0.68
Rabi season	$y = -0.006x^5 + 0.327x^4 - 6.127x^3 + 46.94x^2 - 137.26x + 404.48$	0.47

Thus, rainfall data patterns have shown periodicity in addition to linearity on inter-periodical basis, suggesting that suitable varietal selections are to be made for different rainfall epochs.

Weekly profiles of climatologic variables

The above analysis is useful for choosing a cultivar. On the other hand once the crop is taken up, for weather based advisory development it is required to have information on the weather variables during the crop season. In this context, the weekly weather data for Bijapur Centre, at the heart of the sorghum growing area, is presented here.

The averages (1991-2013) of weekly weather variables at Bijapur are given in Fig 2.11. The most assured and high rainfall is noticed during SMW 38-42, which is the main rainfall period of the region. This march of rainfall suggests that, the rainfall during SMW 35 and SMW 38-42 is the optimum sowing window. The *rabi* season possesses an extended near rainless period after SMW 42, thereby indicating the critical role of other meteorological variables.

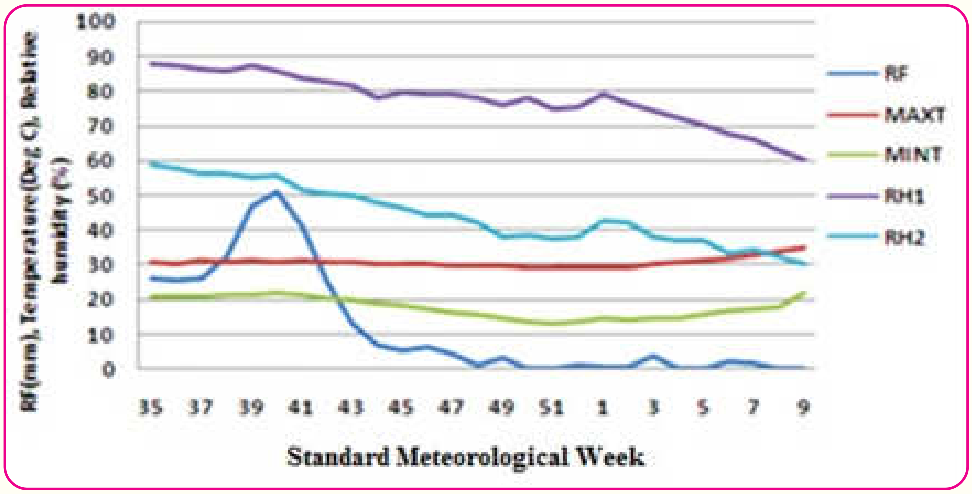


Fig 2.11 Weekly profiles of meteorological parameters at Bijapur during *rabi* crop growing season.

From Fig 2.11 it is also observed that, the maximum temperature is around 30°C during the entire *rabi* season, while the weekly minimum temperature varies between 21°C in the beginning, 13°C in the middle and 19°C towards the end of season. In case of relative humidity, it is noticed that morning time (RH1) decreases from nearly 90% in the beginning of the season to 60 % at the end. The afternoon (RH2) decreases from 60% in the beginning of the season to 30% at the end of the season.

Assuming that the variations in weather variables amount to production level differences of various crops, the following factors can be expected to play a guiding role in determining growth and yield in *rabi* sorghum.

- Persistence of assured rainfall (time of commencement and cessation of rainfall)
- Variation in temperature and relative humidity during the reproductive phase after cessation of rainfall.

Characteristics of meteorological variables

The characteristics of weekly rainfall, temperature (maximum and minimum), relative humidity (morning and afternoon) are given in Figs. 2.12, 2.13 and 2.14 respectively. In these figures, highest indicates the highest weekly event during the period 1992-2013, while the lowest indicates the lowest weekly event during the period. This gives the extremes that were experienced in case of individual parameters. This type of information can be useful in developing weather based crop insurance products.

Rainfall

It is noticed from Fig. 2.12 that, during the climatological period, highest rainfall received during SMW 39, 40 and 41 was more than 150 mm, while during SMW 36, 37 and 38 highest rainfall received exceeded 10mm. In the month of November, highest rainfall reached 100mm in SMW 46. In SMW 48, 50,1,2, 4 and 5 highest rainfall received never reached even 10mm.

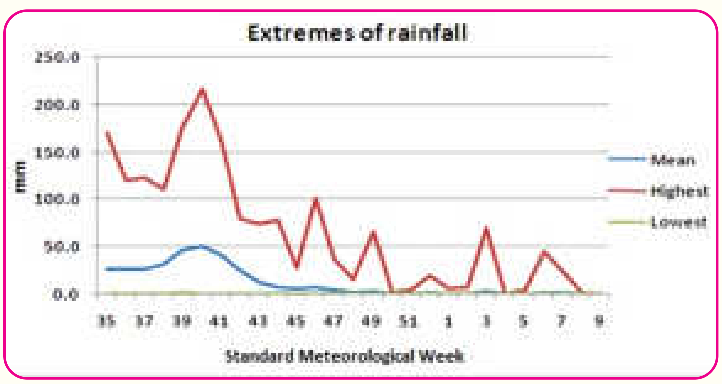


Fig 2.12 Characteristics of weekly rainfall at Bijapur

Weekly temperature

a) Maximum temperature

The characteristics of weekly maximum temperature are given in Fig 2.13a. During the past 20 years the maximum temperature was highly variable in SMW 40 (27 to 35 °C). The risk level of maximum temperature can be gauged by the highest and lowest values depicted for each week. The week numbers 40, 44, 50 and SMW 2 and 3 are noticed to be risky in view of the large variations.

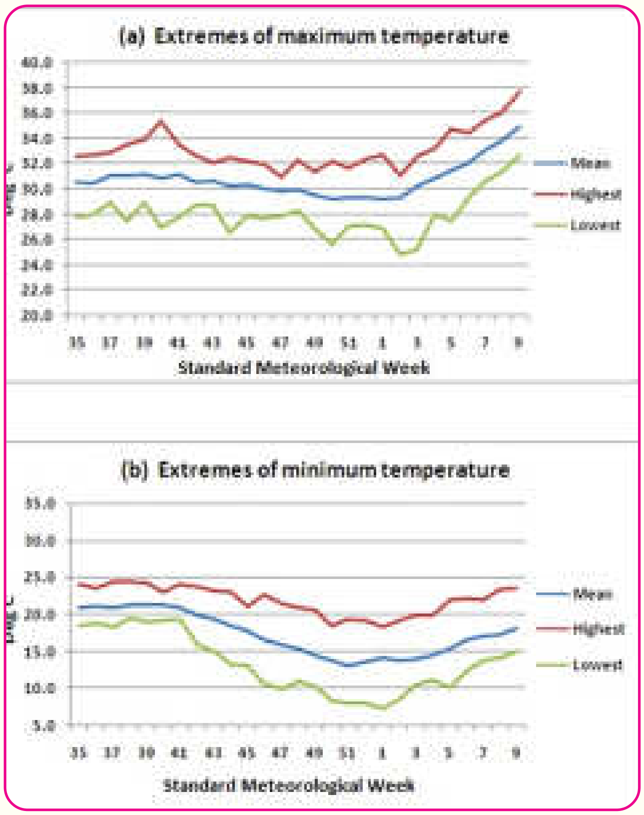


Fig 2.13 Characteristics of weekly temperature at Bijapur

b) Minimum temperature

The temporal variations of weekly minimum temperature are shown in Fig 2.13b. The mean weekly minimum temperature ranged between 20 °C and 23 °C from SMW 36 to SMW 43. It fell below 20^{0}C in SMW 44, reaching a low value of 14.5 °C during SMW 51, 52, 1 and 2 and once again reached to 20 °C in SMW 10. The very low minimum temperatures of 10 °C or less in individual years are important for *rabi* sorghum crop because the crop would experience temperatures less than its base temperature. Chances of prevailing low temperatures (<10 °C) are likely to be high during 47 to 52 SMW and again during SMW 1 to 5.

Relative humidity

a) Morning relative humidity

In the generally decreasing profile of morning humidity, the aberrations in individuals are: extreme high value in SMW 51, extremely low values of less than 60% during SMW 48 to SMW 1. Such low values have the capability to increase desiccation in the crop.

b) Afternoon relative humidity

Similarly in the afternoon also, extremely high values in SMW 1 and SMW 3 and extremely low values of less than 20% in mid December weeks of SMW 50-51 are noticed. Such deviations enhance the risk of desiccation and thereby resulting in low crop yields.

The genotypes which show critical responses to any of these variables in respective weeks can be termed to have higher risk levels.

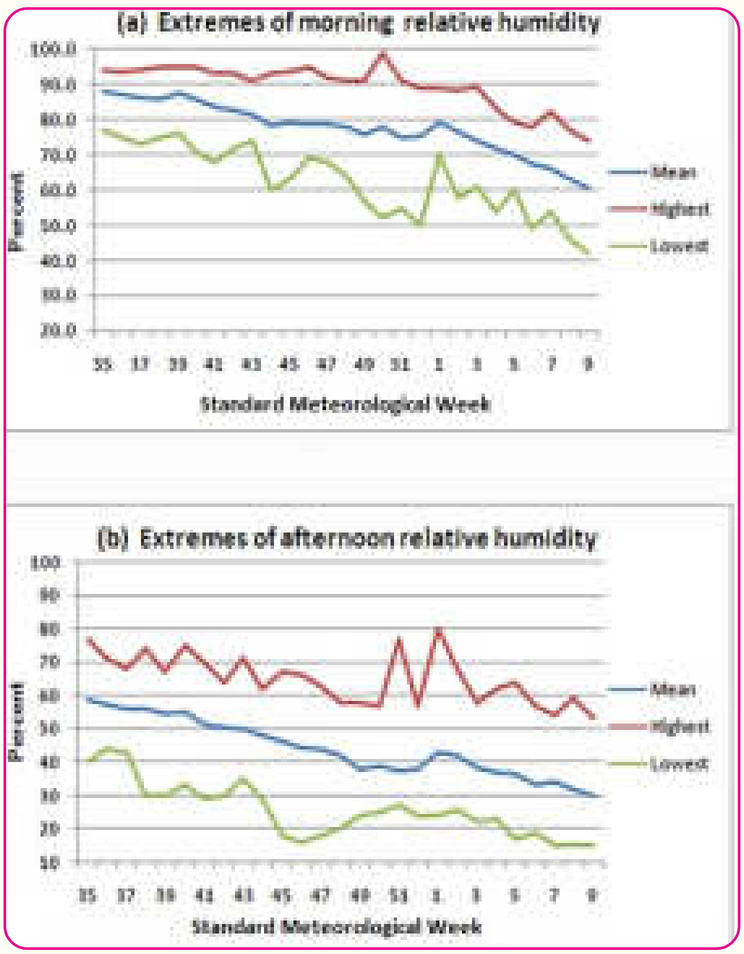


Fig 2.14 Characteristics of weekly relative humidity at Bijapur

3. Crop Weather Relation Studies

The climate of northern Karnataka has shown considerable variability during the 20th century during the *rabi* season. In view of these, the response of different *rabi* sorghum varieties would have changed from time to time and resulted in varied preferences by the farmers.

Selection of cultivars *vis á vis* climate variations: A historical view

As mentioned earlier, the regions showed cyclic variations in rainfall during the historical period. With the intention of knowing whether farmers used the same variety of *rabi* sorghum, or they changed the variety from time to time, and if so why. Opinion of the farmers in the important *rabi* sorghum growing districts of Bellary, Bijapur and Raichur was obtained. The information is presented in Fig 2.13. Sometimes the same farmers have used more than one cultivar, and as such, the sum of the percentages could go beyond 100, whereas in some cases the sum of percentages came out to be less than 100%, since no farmer had taken up to sorghum farming or were not aware of the name or type of variety used.

Bellary District

Earliest *rabi* sorghum varieties were 'Gundudeni' meaning round earhead, and 'Doddajola' indicating bold seeds. There was no other variety available. Doddajola sustained a little till 1980, while Gundudeni prevailed till 1990. These two varieties were acceptable only to a maximum of 22.2%. Two varieties 5-4-1(and H-4 were introduced by farmers in 1970s, but did not sustain even for two decades. On the other hand M35-1, which entered the farmers' fields during 1960s improved its acceptability to 33% during 1970s. Since 1980s it has been accepted or grown by nearly 78% of the surveyed farmers. Meantime, variety SPV –86 was introduced to the farmers during 1980s (13%), but its acceptability was reduced to 7% during 1990s.

Bijapur District

The survey with the farmers of the district indicated that Gundudeni was popular since 1940s in the district. From 33% during this period, the acceptability of this variety increased to 66% during 1970s, thereafter falling to 20% in the 1980s. On the other hand, acceptability of M35-1, which was introduced by farmers during late 1950s (3%) increased to 96% during 1990s. No other varieties could sustain against this.

Raichur District

In Raichur district, acceptability of Gundudeni was 11 to 13% in 1940s and 1950s.

Its rating increased to 60% in 1960s and to 89% in 1970s. Its acceptability decreased sharply to 57% in 1980s and it was negligible in 1990s. The released variety of 109-R was acceptable at 2.2% in 1980s, but was discarded later on. CSV-216R showed 2.2% acceptability at the turn of the century. On the other hand M35-1 was acceptable to farmers of Raichur district at 11.1% during 1970s, and at least to 80% in 1980s and later.

Thus, the variety M35-1 has dominated varietal selection by farmers.

Reasons ascribed by farmers for genotype selection

- Farmers used Gundudeni variety during 1940-70 because it was the best available in terms of drought resistance and good quality of fodder and grain.
- Released varieties, viz., SPV-86 and 109-R were not continued for longer periods, because of drastic yield reduction after 2 or 3 years, perhaps due to changes in rainfall patterns. Also, SPV-86 had the limitation of susceptibility, non-availability of the seeds resulting in its discontinuance.

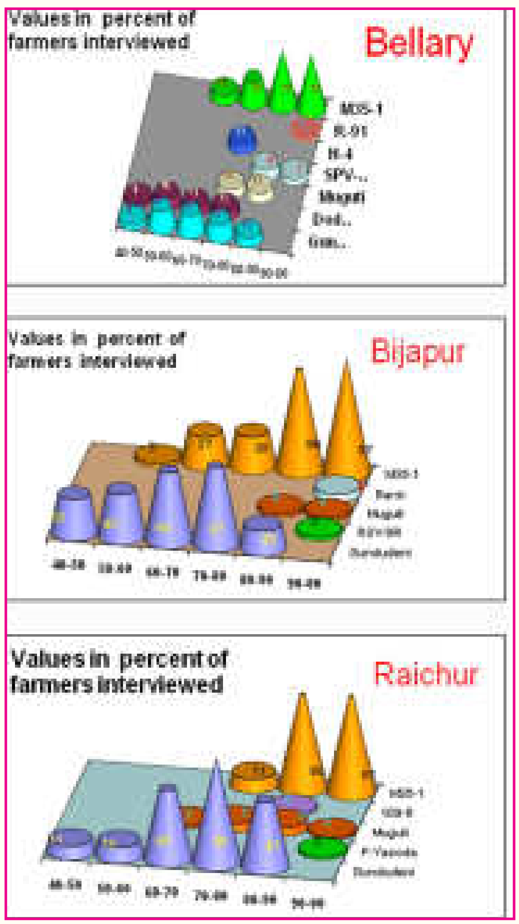


Fig 3.1 Decadal profiles of farmers' acceptability of various genotypes

- The farmers opted to cultivate M35-1, as they found it to be a high yielder having bold seeds and good fodder quality, in addition to being a drought resistant variety and fetching better market value.

- Gundudeni was replaced by M35-1, particularly because the former was susceptible to insect damage to earhead.

- Farmers preferred drought resistant variety because of terminal stress if rainfall ends early.

Parallelly, scientists of UAS, Dharwad were also contacted and the popularity levels of the genotypes were ascertained. The information provided indicates that, 5-4-1(variety showed maximum popularity in late 1980s (50%). Otherwise its popularity rating remained at 33% from 1950s till 2000. The popularity score of 16.6% was recorded for local varieties in 1940s and for Barsi variety in late 1990s. Popularity rating of M35-1 increased from 33.3% in 1940s to 66.6% in 1950s and early sixties, 83% from late 1960s till early 1990s. It acquired 100% popularity by the turn of the century.

It is noticed that the farmers do not adopt new varieties as soon as they are released (i.e., with minimum time gap), and also only a limited number of them adopt it. Because of this time gap mentioned, there is always a possibility that, due to climate variability, the farmers might take up a new variety under relatively adverse climate epochs, thereby making them vulnerable to the altered climate scenario, and reject them straight away in view of its poor performance. This perhaps could be the reason why some of the recently developed genotypes have failed in farmers' field.

As per the information provided by the AICSIP Scheme, the sorghum genotypes can be categorized for different criteria of biotic and abiotic situations as :

Rabi sorghum genotypes recommended for abiotic stress tolerance

• Drought tolerance	Var. M35-1 (*Maldandi*)
	Var. 5-4-1 (*Muguti*)

Rabi sorghum genotypes promising under optimum soil moisture conditions

• Favorable soil moisture	Var. SPV-86
	Var. DSV-4 (9-13)
	Var. DSV-5 (GRS-1)
	Var. CSV-216R (*Phule Yashoda*)
	Var. BJV 44

If we look back to the rainfall variability patterns of September and October, we had noticed alternate epochs of high and low October rainfall. Since, the crop is grown under receding soil moisture situation, low rainfall in October would result in terminal moisture stress while higher rainfall in the month would provide favorable soil moisture situation. When we synchronize the genotypic characteristics with rainfall epochs of October, it can be inferred that in epochs of low September and high October rainfall, genotypes that perform better under favorable soil moisture be opted. From among the genotypes mentioned, the cultivars SPV-86, DSV-4, DSV-5, CSV-216R could be used in high October rainfall epochs. On the other hand, the drought tolerant varieties 5-4-1and M35-1 should be used during epochs of high September and low October rainfall.

Further, in the days leading to climate change, it is more important to have improved drought tolerant varieties.

In view of the above, it is necessary that:

- Cultivars should be preserved for future climate scenarios similar to the ones in which they were developed.
- Cultivars need to be developed with the objective: Specific cultivars for specific rainfall epochs approach.

This would help in sustaining the *rabi* sorghum yields in the future climate change scenarios.

Such an outlook in terms of climate can invariably reduce the yield reductions that may arise because of use of inappropriate varieties during adverse climate epochs to them.

Findings from field experimentations

Field experiments were conducted at Regional Agricultural Research Station, Bijapur under AICRP on Agrometeorology on *rabi* sorghum crop to assess the role of weather on *rabi* sorghum.

Experiments were conducted on the dominant variety Cv.M35-1 (Maldandi), 5-4-1(Muguti), DSV-4 and DSV-5 during the period 1997-2003, and on varieties M35-1, RSLG-262 and CSV-216R during 2004-2009. The genotypes were sown on staggered dates during the recommended sowing period. Since we are using the weather during the crop growing period as a variable, we use the term 'Growing Environment' rather than the 'Date of sowing' as such. So, the number of growing environments would equal the total sowing dates in all the years of experimentation.

Daily meteorological data were collected from the Agrometeorological observatory of the Regional Agricultural Research Station, Bijapur and were converted as means for individual weeks after sowing (WAS) for each growing environment. However, in case of rainfall, sunshine duration and GDD, the accumulations of respective parameters were computed for each week. Correlation analysis was performed for identifying important associative meteorological variables with respect to grain yield of *rabi* sorghum. The identified variables were considered as model parameters in quantifying the yield of corresponding genotypes.

Weekly weather v/s grain yield

Correlation analysis was performed between sorghum grain yield and the different agrometeorological parameters during progressive age of the crop (Table 3.1). It is noticed that rainfall during 4th, 6th, 8th and 9th WAS is positively correlated with yield. The yield is influenced negatively by the maximum temperature throughout the growing season and more strongly during the reproductive period of 9th to 11th WAS. Since the sorghum crop is grown under receding soil moisture conditions, the thermal stress during the reproductive phase would affect grain development, resulting in lower yields.

Table 3.1 Association between grain yield of *rabi* Sorghum and weekly meteorological parameters during the crop growing season

Parameter	Week after sowing												
	1	2	3	4	5	6	7	8	9	10	11	12	13
RF	.31	-.02	.23	.32	.18	.35	.18	.35	.42	.21	.25	-.03	-.09
MaxT	-.03	-.16	-.21	.02	-.23	-.30	-.42	-.26	-.55	-.59	-.53	-.35	-.28
MinT	.24	.33	.23	.16	.46	.29	.08	.43	.33	.51	.38	.03	.00
RH1	-.33	.45	-.16	-.11	.24	.16	.27	.42	.20	.03	.20	.35	.53
RH2	-.41	.17	.24	-.31	-.18	-.38	-.27	-.24	-.22	-.26	-.36	-.52	-.33
MAI	.16	.10	.12	.35	.24	.36	.40	.53	.44	.42	.32	.46	.03

On the other hand the relative humidity in the morning hours was generally positively correlated with grain yield, whereas afternoon values were negatively associated. Relative association during primordial initiation stage suggests atmospheric stress through higher evaporative demand caused by lower relative humidity is harmful at this stage. Moisture availability index (MAI), which takes into account the moisture supply (rainfall), soil moisture variations and atmospheric demand (potential evapotranspiration), almost throughout the growing season, are associated positively with final sorghum grain yield, in particular, commencing from 4 WAS. The MAI in the 8th WAS is best associated with yield (r=.53) indicating agrometeorological requirement during the panicle stage to flowering initiation. It may therefore be inferred that the sorghum crop requires good moisture conditions and less atmospheric demand in the 4th, 6th, 8th and 9th WAS, whereas its yield may be reduced by adverse thermal stress in the reproductive phase (9th-11th WAS).

A yield prediction model for *rabi* sorghum based on the moisture availability index in the 8th WAS was developed, and is given below.

Grain yield (kg/ha) = 1130.4 + 14.16 * MAI (8)

Where, MAI (8) = Moisture availability index in 8th WAS.

Correlation analysis for individual genotypes

Results of correlation analysis performed between grain yield in four different genotypes of *rabi* sorghum and the weekly meteorological variables during crop growing period is presented in Table 3.2(a) M35-1, (b) 5-4-1, (c) DSV-4 and (d) DSV-5. It is observed that rainfall during the 4-5 WAS is important for all genotypes. The maximum temperature has good association in 10 WAS in case of M35-1, 5-4-1 and DSV-4, in 2 WAS in case of DSV-5 and DSV-4. Higher maximum temperature in 7 WAS has an adverse role in DSV-5. Minimum temperature in 5 WAS has a positive association with yield in all varieties except DSV-5. Lowering of minimum temperature during 12 to 14 WAS in general and 14 WAS in particular has a role in increasing the sorghum grain yield. The yield is positively associated with morning vapour pressure during 5, 6 and 8 WAS and with both morning and afternoon cloud cover during 4 and 5 WAS in M35-1 and 5 to 7 WAS in 5-4-1 genotype. On the other hand, in case of DSV-5 genotype the yield is associated with morning cloud cover in 6 to 8 WAS and with afternoon cloud cover in 5 to 6 WAS, whereas the associations are good in 6 to 7 WAS with morning and in 4 to 6 WAS with afternoon values of vapour pressure respectively in Cv. DSV-4.

Thus, type and time of response of various weather variables determined the genotypic response to weather and therefore on yield. This has promoted us to develop yield prediction models separately for each of the cultivar assessed.

Table 3.2(a): Correlation coefficients between grain yield and weekly meteorological variables (Var. M35-1)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MAXT	0.28	0.44	0.24	0.08	0.16	-0.11	-0.47	0.07	-0.30	0.62	0.36	0.08	0.42	0.06
MINT	0.55	0.46	0.58	0.45	0.76	0.54	0.20	0.58	-0.05	0.07	0.08	-0.78	-0.69	-0.90
VP1	0.53	-0.38	0.57	0.47	0.79	0.73	0.22	0.73	0.05	0.41	0.25	-0.53	-0.38	-0.80
VP2	-0.24	-0.81	0.04	0.29	0.52	0.36	0.65	0.82	0.69	0.59	0.33	-0.57	-0.79	-0.75
RH1	0.17	-0.59	0.22	0.38	0.71	0.52	0.35	0.03	0.47	0.20	0.46	0.49	-0.06	0.01
RH2	-0.25	-0.68	0.07	0.26	0.47	0.43	0.68	0.89	0.78	0.50	0.30	-0.53	-0.77	-0.52
TR	-0.09	-0.03	-0.30	-0.29	-0.70	-0.48	-0.34	-0.53	-0.11	0.19	0.04	0.79	0.77	0.87
RHR	0.66	0.43	0.10	-0.09	0.38	-0.18	-0.66	-0.72	-0.70	-0.30	-0.15	0.73	0.76	0.68
BSS	-0.38	-0.11	-0.49	-0.48	-0.82	-0.58	-0.34	-0.53	-0.64	0.44	0.32	0.36	0.56	0.41
Rainfall	-0.37	0.35	-0.07	0.60	0.70	-0.15	-0.37	0.33	-0.31	-	-	-	0.26	-
GDD	0.58	0.54	0.61	0.69	0.71	0.54	0.06	0.46	0.04	0.24	0.17	-0.80	-0.59	-0.47

Table 3.2(b): Correlation coefficients between grain yield and weekly meteorological variables (Var. 5-4-1)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MAXT	0.29	0.49	0.29	0.04	0.21	-0.17	-0.45	0.11	-0.30	0.62	0.40	0.11	0.47	0.05
MINT	0.55	0.46	0.60	0.47	0.76	0.55	0.15	0.62	-0.05	0.02	0.04	-0.77	-0.64	-0.88
VP1	0.51	-0.34	0.57	0.49	0.78	0.73	0.17	0.77	0.06	0.38	0.23	-0.52	-0.34	-0.78
VP2	-0.26	-0.79	0.02	0.31	0.52	0.38	0.64	0.84	0.71	0.59	0.32	-0.58	-0.78	-0.75
RH1	0.17	-0.57	0.20	0.39	0.69	0.51	0.30	0.06	0.48	0.21	0.48	0.47	-0.07	0.01
RH2	-0.26	-0.68	0.03	0.29	0.47	0.46	0.66	0.90	0.80	0.49	0.27	-0.54	-0.76	-0.52
TR	-0.08	0.00	-0.28	-0.31	-0.68	-0.51	-0.29	-0.55	-0.11	0.24	0.09	0.80	0.75	0.84
RHR	0.68	0.48	0.14	-0.12	0.36	-0.22	-0.67	-0.71	-0.73	-0.29	-0.12	0.73	0.74	0.69
BSS	-0.37	-0.08	-0.45	-0.49	-0.78	-0.60	-0.34	-0.50	-0.58	0.46	0.36	0.32	0.54	0.41
Rainfall	-0.38	0.33	-0.05	0.61	0.65	-0.14	-0.37	0.38	-0.32	-	-	-	0.28	-
GDD	0.59	0.57	0.66	0.68	0.70	0.53	0.02	0.51	0.05	0.21	0.15	-0.79	-0.53	-0.40

Table 3.2(c): Correlation coefficients between grain yield and weekly meteorological variables (Var. DSV-5)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MAXT	0.14	0.54	0.21	0.15	0.00	0.01	-0.67	-0.02	-0.25	0.42	0.01	-0.16	0.26	0.40
MINT	0.13	0.00	0.27	0.20	0.56	0.06	-0.07	0.36	-0.19	-0.11	0.16	-0.64	-0.56	-0.69
VP1	0.27	-0.66	0.26	0.32	0.59	0.34	-0.01	0.62	-0.16	0.14	0.14	-0.40	-0.12	-0.92
VP2	-0.10	-0.89	0.03	0.20	0.81	0.56	0.61	0.51	0.44	0.36	0.20	-0.50	-0.67	-0.77
RH1	0.19	-0.74	0.06	0.45	0.68	0.34	0.42	0.31	0.25	0.13	0.26	0.40	0.27	-0.15
RH2	-0.11	-0.84	0.06	0.16	0.77	0.58	0.69	0.60	0.54	0.31	0.20	-0.40	-0.64	-0.70
TR	0.03	0.37	-0.07	-0.09	-0.55	-0.05	-0.11	-0.34	0.05	0.29	-0.15	0.56	0.58	0.88
RHR	0.43	0.50	-0.02	0.13	0.11	-0.48	-0.62	-0.34	-0.52	-0.19	-0.12	0.57	0.77	0.81
BSS	-0.32	0.23	-0.38	-0.37	-0.71	-0.66	-0.57	-0.65	-0.51	0.51	0.21	0.11	0.30	0.64
Rainfall	-0.46	0.04	-0.16	0.44	0.60	-0.42	-0.42	0.25	-0.40	-	-	-	0.44	-
GDD	0.20	0.47	0.35	0.39	0.73	0.07	-0.22	0.48	-0.20	0.06	0.15	-0.82	-0.37	-0.57

Table 3.2(d): Correlation coefficients between grain yield and weekly meteorological variables (Var. DSV-4)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
MAXT	0.36	0.60	0.45	-0.13	0.37	-0.22	-0.32	0.16	-0.25	0.70	0.55	0.17	0.64	0.05
MINT	0.55	0.50	0.63	0.56	0.71	0.62	0.10	0.69	-0.04	0.01	0.05	-0.67	-0.54	-0.80
VP1	0.45	-0.23	0.55	0.55	0.72	0.74	0.11	0.86	0.07	0.36	0.29	-0.42	-0.35	-0.69
VP2	-0.32	-0.75	-0.05	0.39	0.46	0.39	0.58	0.86	0.74	0.66	0.35	-0.55	-0.75	-0.69
RH1	0.12	-0.53	0.09	0.44	0.60	0.48	0.16	0.13	0.50	0.13	0.51	0.46	-0.19	-0.03
RH2	-0.34	-0.68	-0.08	0.40	0.35	0.48	0.55	0.90	0.81	0.54	0.29	-0.53	-0.76	-0.49
TR	-0.03	0.05	-0.21	-0.44	-0.59	-0.58	-0.20	-0.61	-0.09	0.29	0.13	0.78	0.74	0.77
RHR	0.77	0.54	0.18	-0.25	0.36	-0.26	-0.62	-0.68	-0.72	-0.36	-0.13	0.73	0.69	0.61
BSS	-0.30	0.01	-0.32	-0.54	-0.64	-0.55	-0.23	-0.43	-0.41	0.46	0.37	0.18	0.55	0.40
Rainfall	-0.41	0.28	-0.01	0.71	0.51	-0.09	-0.38	0.56	-0.31	-	-	-	0.22	-
GDD	0.65	0.68	0.79	0.68	0.68	0.58	0.01	0.61	0.09	0.21	0.19	-0.71	-0.39	-0.23

Yield models for sorghum genotypes

Using the above information from correlation analysis, regression models were developed for predicting of grain yield of *rabi* sorghum genotypes were developed, and are presented in Table 3.3. It is seen that the coefficient of determination is very high, ranging from 0.93 for M35-1 to 0.99 for DSV-5. In view of the fewer cases and many variables selection of variables becomes very difficult.

Table 3.3: Yield prediction models for sorghum genotypes

Genotype	Model No.	Model	R^2
M35-1	1	Y= 1.62(RF5)+1.99(RH28)+282.4(TX10)- 151.6(TN12)-60009.2	0.93
	2	Y= - 18.9(RH28)+560.9(TX10)- 324.2(TN12)+119.7(TN14)-13033.4	0.94
5-4-1	1	Y= - 80.6(VP22)-0.656(RF4)+3.16(BSS5)+ 33.0(RH28)+598.2	0.97
	2	Y= - 79.4(VP22)-60.7(BSS5)+34.8(RH28)+ 51.0(TN14)+355.3	0.98
DSV-5	1	Y= -83.2(VP22)-0.031(RF5)-87.3(BSS6)-10.3(GDD12)+ 3609.1	0.99
	2	Y= - 76.3(VP22)-86.8(BSS6)-9.63(GDD12)- 18.4(VP114)+3643.2	0.99
DSV-4	1	Y= - 43.6(VP22)+1.61(RF4)+19.5(BSS5)+ 28.4(RH28)-20.8	0.96
	2	Y= - 66.5(VP22)+19.3(BSS5)+32.3(RH28)+18.3(TN14)-10.1	0.95

Where,

RF4, RF5=Rainfall during the 4th week after sowing (4 WAS) and 5 WAS respectively

TN12, TN14=Minimum temperature during 12 WAS and 14 WAS respectively

TX10=Maximum temperature during 10 WAS

BSS5, BSS6= Sunshine duration in 5 WAS and 6 WAS respectively

RH28=Afternoon relative humidity during 8 WAS

VP22=Afternoon vapour pressure during 2 WAS

It is noticed that generally the model parameters are afternoon vapor pressure in 2 WAS, afternoon relative humidity in 8 WAS, sunshine duration in 5 WAS or 6 WAS, rainfall during 4 WAS or 5 WAS, and minimum temperature or vapor pressure in 14 WAS.

Table 3.3 contains two sets of models under model No.1 and model No. 2 for each genotype. In the first set rainfall is considered as one of the model parameters. However, climatologically, rainfall occurs rarely after 15th October. Hence, the second sets of models were developed without considering rainfall as a model parameter. Both the sets have same levels of R^2 for individual genotypes. Hence, the models not using rainfall as model parameter can be preferred.

Influence of stage wise weather prevalence on yield of *rabi* sorghum genotypes

Data from six years of experimentation from 2004-05 to 2009-10 were analyzed through statistical methods, and correlation analysis was performed between meteorological variables prevailing in individual physiological stages and grain yield of three *rabi* sorghum genotypes namely, M35-1, RSLG-262 and CSV-216R.

The results of correlation analysis are presented in Tables 3.5, 3.6 and 3.7 for the varieties M35-1, RSLG-262 and CSV-216R respectively, and the description of terms in these tables are given in Table 3.4 below.

Table 3.4 Description of terms in Tables 3.5, 3.6 and 3.7

Weather variable description	Physiological stage description
MAXT: Maximum temperature (^{o}C)	**G&E:** Germination and emergernce
MINT: Minimum temperature (^{o}C)	**SDL:** Seedling
VP1: Morning vapour pressure (mm Hg)	**PI:** Primordial initiation
VP2: Afternoon vapour pressure (mm Hg)	**Veg:** Vegetative
RH1: Morning relative humidity (%)	**BtLf:** Bootleaf
RH2: Afternoon relative humidity (%)	**FL:** Flowering
TR: Temperature range (^{o}C)	**GF:** Grain filling
RHR: Relative humidity range (%)	**PM:** Physiological maturity
BSS: Bright sunshine duration (h)	**M&H:** Maturity and harvest
RF: Rainfall (mm)	
GDD: Growing degree days (Degree days)	

It is noticed from the Tables 3.5 to 3.7 that primordial initiation stage is the most important in determining their yield levels. Prevalence of higher values of the atmospheric hygric factors, namely, vapor pressure and relative humidity are observed to increase the yield of all the genotypes. The additional factors that influence the yield are, temperature range (negative) and afternoon cloudiness (positive) in case of M35-1, afternoon cloudiness (positive) in case of RSLG-262 and relative humidity range (negative) and morning time cloudiness (positive) in case of CSV-216R variety.

Table 3.5: Correlation coefficients between meteorological variables in crop growth stages and grain yield of *rabi* sorghum Cv. M35-1

Weather	Physiological stage								
variable	G&E	SDL	PI	Veg	BtLf	FL	GF	PM	M&H
MaxT	-0.10	0.23	-0.20	-0.10	0.01	0.01	-0.06	-0.06	-0.09
MinT	0.37	0.21	0.53	0.38	-0.05	-0.21	-0.05	-0.05	0.15
VP1	0.20	0.13	0.70	0.34	0.14	-0.01	0.10	0.10	0.32
VP2	0.26	0.13	0.68	0.40	0.14	0.00	0.09	0.09	0.27
RH1	-0.05	0.01	0.76	0.46	0.37	0.24	0.36	0.36	0.25
RH2	0.18	0.10	0.68	0.31	0.09	0.04	0.13	0.13	0.26
TR	-0.33	-0.10	-0.59	-0.39	0.06	0.23	0.03	0.03	-0.17
RHR	-0.29	-0.16	-0.35	-0.06	0.18	0.19	0.21	0.21	-0.10
BSS	0.33	0.33	0.24	0.36	0.32	0.35	0.33	0.33	0.29
RF	-0.14	-0.05	0.49	0.18	-0.05	-0.09	-0.05	-0.05	0.27
GDD	0.23	0.25	0.40	0.31	0.08	0.03	0.10	0.10	0.18

Table 3.6: Correlation coefficients between meteorological variables in crop growth stages and grain yield of *rabi* sorghum Cv. RSLG-262

Weather	Physiological stage								
variable	G&E	SDL	PI	Veg	BtLf	FL	GF	PM	M&H
MaxT	0.10	0.04	0.19	0.04	0.15	-0.15	-0.09	-0.20	-0.29
MinT	0.23	0.33	0.49	0.24	-0.06	-0.20	0.05	0.54	0.30
VP1	0.00	0.02	0.71	0.10	-0.12	-0.02	0.56	0.56	0.47
VP2	0.12	0.25	0.78	0.27	-0.04	-0.01	0.49	0.49	0.30
RH1	-0.27	-0.14	0.64	0.14	0.00	0.06	0.26	0.26	0.18
RH2	-0.06	0.15	0.75	0.17	-0.08	0.05	0.49	0.49	0.34
TR	-0.10	-0.31	-0.41	-0.22	0.10	0.16	-0.56	-0.56	-0.40
RHR	-0.11	-0.40	-0.57	-0.13	0.10	-0.01	-0.41	-0.41	-0.30
BSS	-0.22	-0.26	-0.34	-0.23	-0.23	-0.23	-0.30	-0.30	-0.29
RF	-0.17	-0.02	0.51	0.10	-0.18	0.02	0.42	0.42	0.05
GDD	-0.07	-0.01	0.21	0.02	-0.12	-0.23	-0.01	-0.01	-0.11

Table 3.7: Correlation coefficients between meteorological variables in crop growth stages and grain yield of *rabi* sorghum Cv. CSV-216R

Weather variable	Physiological stage								
	G&E	SDL	PI	Veg	BtLf	FL	GF	PM	M&H
MaxT	-0.07	0.26	-0.17	-0.08	0.02	0.04	0.00	-0.12	-0.16
MinT	0.36	0.24	0.46	0.43	0.11	-0.13	-0.02	0.31	0.39
VP1	0.20	0.04	0.71	0.42	0.15	0.04	0.21	0.45	0.54
VP2	0.12	0.25	0.80	0.27	-0.04	-0.01	0.26	0.49	0.30
RH1	-0.07	-0.11	0.78	0.55	0.40	0.26	0.46	0.29	0.35
RH2	0.25	0.03	-0.51	0.43	0.18	0.09	0.27	0.43	0.49
TR	-0.31	-0.12	-0.47	-0.43	-0.10	0.16	0.02	-0.33	-0.41
RHR	-0.40	-0.16	-0.60	0.17	0.09	0.14	0.10	-0.29	-0.33
BSS	0.27	0.30	0.17	0.30	0.26	0.30	0.27	0.22	0.22
RF	-0.11	-0.10	0.56	0.32	-0.12	-0.08	0.15	0.29	0.15
GDD	0.27	0.29	0.38	0.36	0.20	0.09	0.15	0.27	0.33

The results are graphically presented in Figs 3.2 – 3.7 for brevity and drawing inferences.

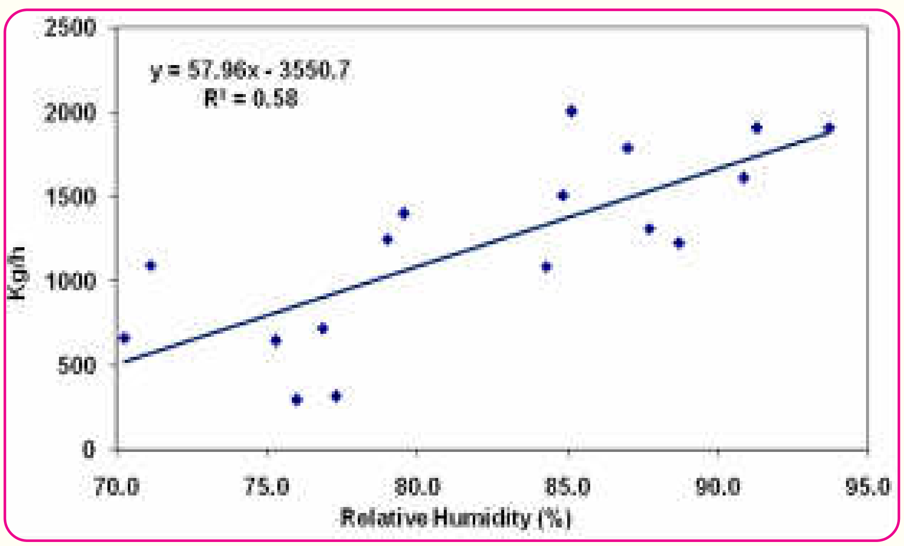


Fig 3.2 : Influence of morning relative humidity during primordial initiation stage on grain yield of sorghum Cv. M35-1

From Fig 3.2, it is noticed that morning humidity in the range of 65 to 95 % during the primordial initiation stage influenced yield of sorghum genotype M35- (M35-1). A linear relationship accounted for 58 per cent of variations.

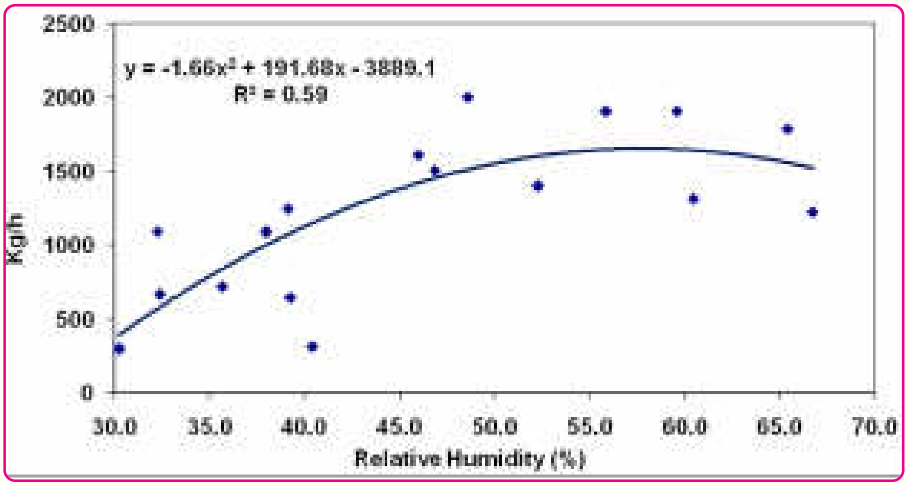


Fig 3.3 : Influence of afternoon relative humidity during primordial initiation stage on grain yield of sorghum Cv. M35-1

In case of afternoon relative humidity during the primordial initiation stage, the genotype M35-1 showed a polynomial relation accounting for 59 per cent of variation (Fig 3.3). This suggests excessive afternoon humidity could also negatively impact the sorghum yields.

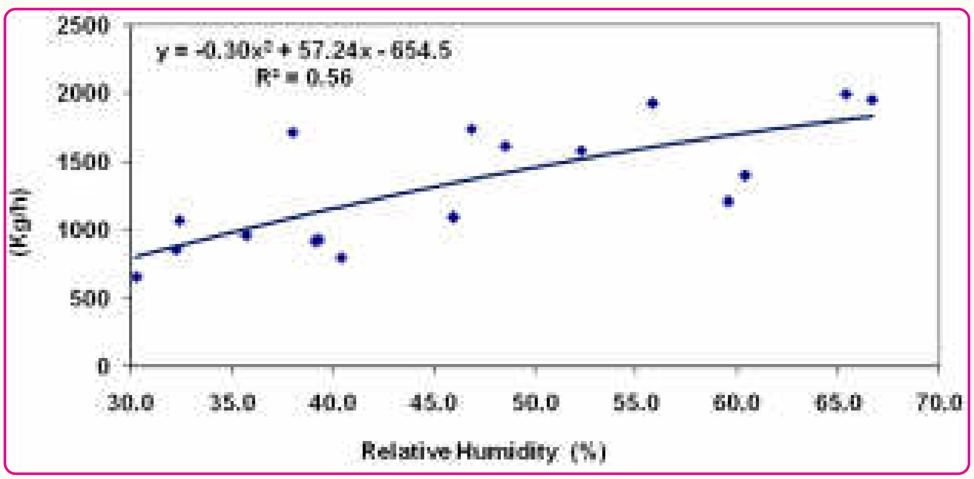


Fig 3.4 : Influence of afternoon relative humidity during primordial initiation stage on grain yield of sorghum Cv. RSLG-262

Sorghum genotype RSLG-262 showed a curvilinear relation with afternoon relative humidity with a coefficient of determination of 0.56 (Fig 3.4). On the other hand, the relationship was linear with afternoon vapor pressure with a coefficient of determination of 0.61 (Fig 3.5)

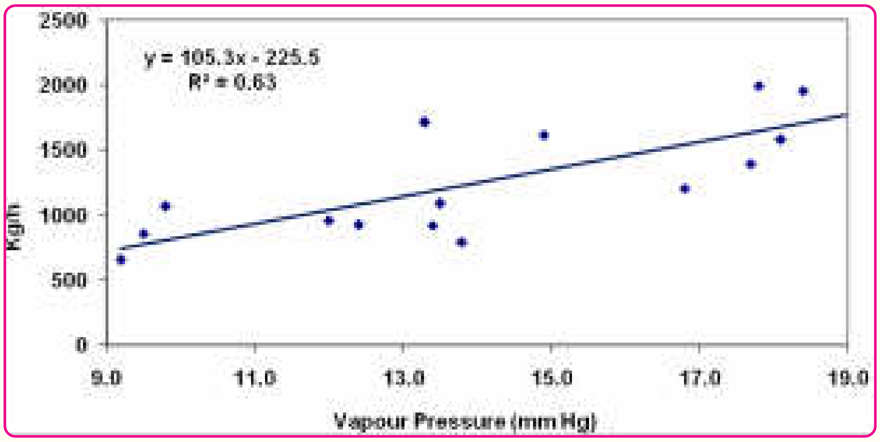


Fig 3.5 : Influence of afternoon vapour pressure during primordial initiation stage on grain yield of sorghum Cv. RSLG - 262

From Fig 3.6 it is noticed that the morning time relative humidity during primordial initiation stage determined yield of sorghum genotype CSV-216R to an extent of 64 per cent through linear association in the relative humidity of 65 per cent to 95 per cent. On the other hand, the afternoon relative humidity in the range of 30 per cent to 70 per cent showed linear relationship with grain yield of sorghum genotype CSV-216R accounting for 62 per cent of variability (Fig 3.7).

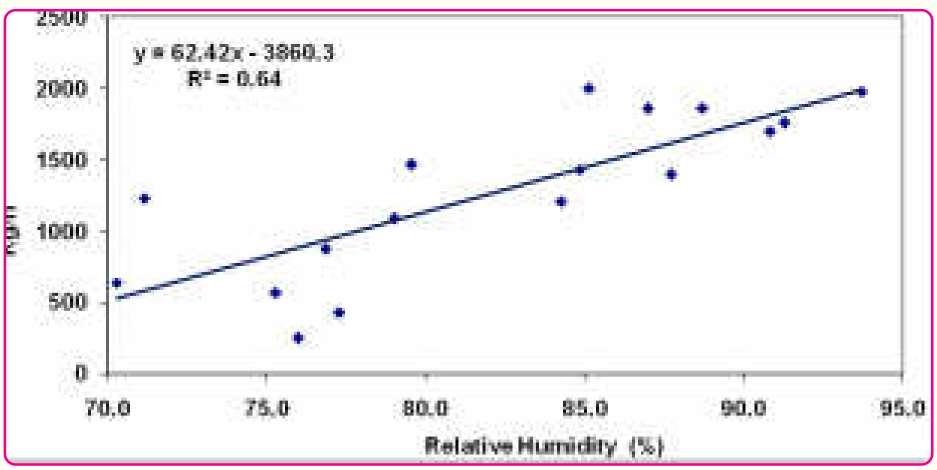


Fig 3.6 : Influence of morning relative humidity during primordial initiation stage on grain yield of sorghum Cv. CSV-216R

From the above figures the following information regarding the unfavourable weather situations in panicle initiation stage of *rabi* sorghum resulting in yield of less than 1000 kg/ ha was derived.

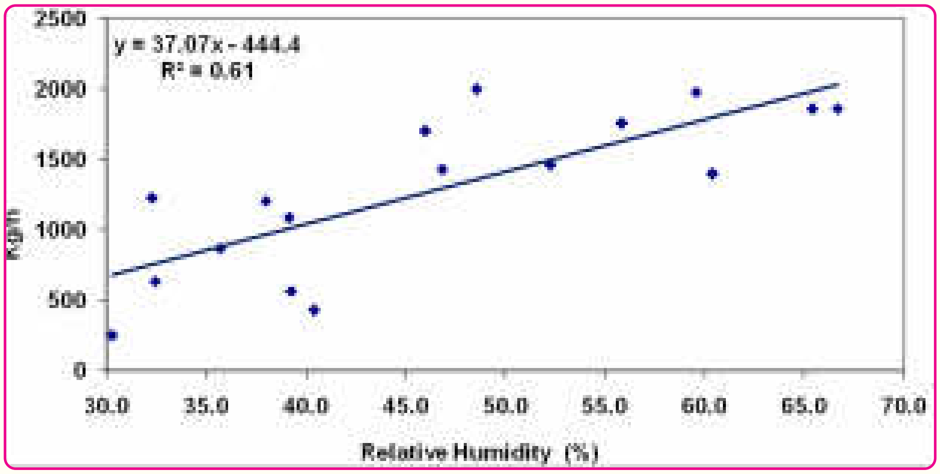


Fig 3.7 : Influence of afternoon relative humidity during primordial initiation stage on grain yield of sorghum Cv. CSV-216R

Weather variable	M35-1	RSLG - 262	CSV-216R
RH1	<77%	-	<77%
RH2	<42%	<42%	<42%
VP2	-	<14 mm Hg	<14 mm Hg

In order to quantify these results, yield prediction models were developed for the popular variety M35-1 (Table 3.8).

Table 3.8: Yield prediction models for Sorghum Cv. M35-1

Model No.	Meteorological variable(s)	Models	R
1	Morning relative humidity	Y = 57.8 RH1– 3546.3	0.76
2	Diurnal range of temperature, rainfall	Y= -85.8 TR + 21.6RF+2284.6	0.69
3	Rainfall, Minimum temperature	Y=76.0 MinT +21.9RF- 180.5	0.64

4. Crop Growth Modelling Studies

Crop growth analysis

The dry matter partitioning components of sorghum genotypes, viz, M35-1, DSV-5 and DSV-4 indicated that the dry matter continued to increase till 90 DAS.

Correlation analysis was performed for identifying important associative meteorological variables with respect to crop growth in terms of biomass and grain yield of *rabi* sorghum. The identified variables were considered as model parameters in quantifying the crop parameters.

Correlation analysis between growth in *rabi* sorghum and meteorological variables:

The daily meteorological data were also used to compute the stage wise means/ summations for the different meteorological variables as explained in the previous chapter, but for the stages mentioned below. The stage wise data computations were made for the periods 0-30 DAS (seedling stage), 31-45 DAS (primordial initiation stage), 46-60 DAS (flag leaf stage), 61-75 DAS (flowering stage), 75-90 DAS (grain filling stage).

The biometric parameters, namely, leaf dry weight, stem dry weight, earhead dry weight and total dry weight were collected from 3 plant samples from each experimental plot at 30, 45, 60, 75, and 90 DAS and converted to g/m^2. From the data collected, the accumulations (growth) of individual dry matter components in each stage were computed and presented in g/ m^2. The final pod and grain yield data were collected from net plot and presented in kg/ha for analysis.

For example, if L30 and L45 DAS are the leaf dry weight at 30 and 45 DAS respectively, the growth of leaf during 31-45 DAS is computed as L45- L30. The growth of each parameter is computed in individual stages for each genotype using this procedure.

Modeling of the growth of individual dry matter components is performed as a function of:

a) Weather influences in the given stage

b) Dry matter accumulation till the end of previous stage.

Accordingly, correlation analysis between growth of individual dry matter components on one side and agrometeorological variables and individual dry matter components on the other is performed. The best related variables are identified and used as independent variables for development of regression models for individual growth parameters, namely, leaf growth, stem growth and earhead growth in various stages of different genotypes of *rabi* sorghum.

Results of correlation analysis between crop parameters and meteorological variables are described below for the variables with significant relationships.

Cv. M35-1

Seedling stage:

The leaf growth during 0-30 DAS in cultivar M35-1 is significantly correlated with maximum temperature (r = 0.90), pan evaporation (r = 0.85), afternoon relative humidity (r = -0.66). The stem growth during this stage has good association with afternoon relative humidity (r = -0.76) and relative humidity range (r = 0.73). Growth of the dry matter components in this stage is seen to be associated with the afternoon weather parameters.

Primordial initiation stage:

The leaf growth in this stage has good association with the leaf dry weight at 30 DAS (r= 0.80) and afternoon vapour pressure (r= 0.65). The stem growth is also significantly correlated with same variables, i.e., leaf dry weight at 30 DAS (r= 0.84) and afternoon vapour pressure (r= 0.71). In this stage also the afternoon weather variable dominated over other parameters.

Flag leaf initiation:

The variables that have good association with leaf growth in M35-1 during 46-60 DAS are, stem dry weight (r = 0.93) and leaf dry weight (r = 0.89) at 45 DAS, afternoon cloud cover (r = -0.84), rainfall (r = -0.72), temperature range (r = 0.70), morning relative humidity (r= 0.55) and minimum temperature (r = -0.62). Similarly, stem dry weight (r = 0.75) and leaf dry weight (r = 0.74) at 45 DAS, afternoon cloud cover (r = -0.76) and temperature range (r = 0.71) are the important variables having good correlation with the stem growth.

Flowering:

The leaf growth has good correlation with leaf dry weight at 60 DAS (r = 0.68), maximum temperature (r = 0.69) and cumulative sunshine duration (r = -0.81). While the association of various weather variables with stem growth is poor, the earhead weight has good association with morning time relative humidity (r = 0.72).

Grain filling:

During this stage, the leaf growth has significant relationship with stem and leaf dry weight at 75 DAS (r = -0.90 for either variable) and pan evaporation (r = 0.71). Conversely to the previous stage, the stem growth is well correlated with the meteorological variables, namely, cumulative sunshine (r = 0.71), morning vapour pressure (r = -0.67), and temperature range (r = 0.52). On the other hand the earhead growth possesses good association with earhead dry weight at 75 DAS (r = 0.88), rainfall (r = 0.94) and afternoon vapour pressure (r = -0.59).

This indicates that strength of the crop in the previous stage has equal role in determining the final yield.

Cv. 5-4-1

Seedling stage:

Best correlations for initial leaf growth in this variety are with maximum temperature (r = 0.96), evaporation (r = 0.69) and growing degree days (r = 0.70), whereas maximum temperature (r = 0.87) and GDD (r = 0.78) are important for stem growth.

Primordial initiation stage:

Leaf growth during this period has the highest association with evaporation (r = 0.62) and maximum temperature (r = 0.51) among meteorological variables, but the best is with the biometric components at 30 DAS (r = 0.88 to 0.90). In case of stem growth, the important variables are the biometric components at 30 DAS (r = 0.94 to 0.96) and to a smaller extent, sunshine duration (r = 0.62), rainfall (r = -0.54) and evaporation (r = 0.69).

Flag leaf initiation:

Once again, the leaf and stem dry weights of the previous stage (0-45 DAS) dominate the associations with both leaf growth and stem growth during 45-60 DAS in 5-4-1 genotype. Also, amongst the agrometeorological variables, sunshine duration (r = 0.73 and 0.76 respectively), morning cloud cover (r = -0.80 and r = -0.82) respectively) and evaporation (r = 0.69 and r = 0.68 respectively) are seen important for leaf growth and stem growth.

Flowering:

Leaf growth during this stage has good associations with leaf and stem dry weight at 60 DAS with an 'r' value of 0.59 for both. Stem growth also has best associations with these variables (r = 0.76 and r = 0.75 respectively), followed by morning cloud cover (r = -

0.59). Pod growth in this stage is well correlated with leaf dry weight (r = 0.83) and stem dry weight (r = 0.86) weight at 60 DAS, evaporation (r = 0.71), morning cloud cover (r = -0.70) and morning relative humidity (r = -0.54).

Grain filling:

Negative association is noticed between leaf growth during this stage and leaf dry weight (r = 0.93), stem dry weight (r = 0.95) and earhead weight (r = 0.96) at 75 DAS. Amongst the meteorological variables GDD has a correlation of r = -0.75. However, the stem growth has good correlation with afternoon relative humidity only (r = 0.71). Pod growth, on the other hand, is seen to be closely associated with atmospheric hygric factors, namely, afternoon vapour pressure (r = 0.84), afternoon relative humidity (r = 0.79) and relative humidity range (r = 0.75). It is also associated positively with earhead dry weight at 75 DAS (r = 0.51).

Cv. DSV-5

Seedling stage:

Higher temperature (r = 0.87), lower afternoon relative humidity (r = -0.72), lower rainfall (r = -0.57) and higher evaporation (r = 0.70) are seen to be favourable for leaf growth in DSV-5 genotype during 0-30 DAS. In case of stem growth the afternoon vapour pressure (r = -0.75) and afternoon relative humidity (r = -0.81) and higher relative humidity range (r = 0.75) are seen to be favourable.

Primordial initiation stage:

Leaf growth has associations of the order of r = 0.56 with leaf dry weight at 30 DAS and r = 0.58 with afternoon vapour pressure. The same parameters have respective correlation coefficients of 0.67 and 0.62 in case of stem growth during 31-45 DAS.

Flag leaf initiation:

The variables noticed to possess good association with leaf growth during this period are leaf dry weight (r = 0.82) and stem dry weight (r = 0.85) at 45 DAS, temperature range (r = 0.63), rainfall (-0.77) and afternoon cloud cover (r = -0.71). The same parameters are important for stem growth also, with respective correlation coefficients of 0.94, 0.97, 0.58, -0.60 and -0.85.

Dependence on same factors by both leaf and stem can make the genotype susceptible to adverse weather conditions in this stage.

Flowering:

During this stage the leaf growth is not associated with the dry matter at 60 DAS. The meteorological variables showing good correlation with leaf growth are, maximum and minimum temperatures (r = -0.70), morning and afternoon vapour pressures (r = 0.67), relative humidity range (r = -0.79), cumulative sunshine (r = -0.81) and GDD (r = 0.79). The leaf growth is seen to be highly weather dependent in this stage. On the other hand, the stem growth has good association with leaf (r = 0.82) and stem dry weight (r = 0.85) at 60 DAS, afternoon vapour pressure (r = 0.72) and afternoon relative humidity (r = 0.69). The earhead growth also shows good association with leaf dry weight (r = 0.87) and stem dry weight (r = 0.89) at 60 DAS. Amongst the meteorological variables, maximum temperature (r = 0.69) and morning vapour pressure (r = 0.60) are seen to be important.

Grain filling:

Leaf growth is seen to be associated poorly with weather variables in this stage, while the associations with the leaf (r = -0.91), stem (r = -0.92) and earhead dry weight (r = -0.85) at 75 DAS are noticed to be the best. Evaporation shows a correlation coefficient of 0.72. In contrast, the stem growth is seen to possess better correlations with meteorological variables, namely minimum temperature (r = -0.73) morning cloud cover (r = 0.73), rainfall (r = 0.65) and GDD (r = -0.77). The leaf dry weight at 75 DAS shows a correlation of r = -0.60 with stem growth.

The earhead growth during 76-90 DAS is associated only with meteorological variables, particularly, minimum temperature (r = -0.88), afternoon vapour pressure (r = -0.77), temperature range (r = 0.70), relative humidity range (r = 0.78) and GDD (r = -0.89). This shows affinity to cooler nights and drier afternoons for better growth of earhead during 76-90 DAS.

Cv. DSV-4

Seedling stage:

In the initial period leaf growth is well associated with maximum temperature (r = 0.95) and evaporation (r = 0.83), while stem growth shows good correlation with maximum temperature (r = 0.71), afternoon relative humidity (r = -0.78) and relative humidity range (r = 0.71).

Primordial initiation stage:

In this stage, leaf growth has best association with afternoon vapour pressure (r=0.61), whereas the stem growth is similarly associated with afternoon vapour pressure (r = 0.75) and afternoon relative humidity (r = 0.63). This suggests complete sensitivity of DSV-4 during this stage to the afternoon hygric factors.

Flag leaf initiation:

During this stage the leaf growth and the stem growth are well associated with leaf and stem dry weight at 45 DAS, with correlation coefficients ranging from 0.91 to 0.97. Amongst the meteorological variables minimum temperature, rainfall, afternoon cloud cover and GDD possessed highly negative correlation with leaf growth and stem growth in this stage.

Dependence on same factors by both leaf and stem can make the genotype susceptible to adverse weather situations in this stage.

Flowering:

Leaf growth during this stage of Cv. DSV-4 is positively correlated with both leaf dry weight (r = 0.74) and stem dry weight (r = 0.81) at 60 DAS. Stem growth during 61-75 DAS has correlations of r = 0.90 and r = 0.94 respectively for the same variables. Except negative correlation of r = -0.74 and r = -0.55 respectively for leaf growth and stem growth, no other meteorological variable has discernable association. It is further noticed that, minimum temperature (r = -0.72), afternoon relative humidity (r = 0.64), temperature range (r = 0.66), sunshine duration (r = 0.66) and GDD (r = -0.68) are the variables associated with earhead growth during this period. The earhead growth has very poor association with dry matter components at 60 DAS.

Thus, the sensitivity of earhead growth to weather variables alone enhances the vulnerability of this genotype to weather extremes in this stage.

Grain filling:

During this stage it is noticed that leaf growth, stem growth and earhead growth are poorly associated with dry matter components at 75 DAS, excepting leaf dry weight (r = -0.74) and stem dry weight (r = 0.60) having good correlation with leaf growth.

Amongst the weather variables, minimum temperature (r = -0.80), rainfall (r = 0.67), morning cloud cover (r = 0.75) and GDD (r = -0.87) are well associated with stem growth, while afternoon vapour pressure (r = 0.86), afternoon relative humidity (r = 0.73), relative humidity range (r = -0.82) and rainfall (r = -0.64) have good correlation with respect to leaf growth. On the other hand morning vapour pressure (r = -0.69), relative humidity range (r = 0.60) and cumulative sunshine duration (r = 0.60) have good association with earhead growth.

This makes the genotype more responsive to weather changes in this stage.

Growth models for *rabi* sorghum genotypes

The regression models developed for crop growth components in different genotypes are presented in Table 4.1.

Seedling stage

Leaf growth:

The leaf growth in this stage is modeled by maximum temperature and pan evaporation for the genotypes M35-1 and DSV-4 and by maximum temperature and afternoon relative humidity for the cultivar DSV-5. This suggests the requirement of higher thermal energy and atmospheric demand for profuse leaf and stem growth. The models have R^2 values between 0.76 and 0.90.

Stem growth:

The stem growth is modeled by afternoon relative humidity for M35-1 ($R^2 = 0.58$), after noon relative humidity and relative humidity range for DSV-5 (R^2=0.77), and maximum temperature, afternoon relative humidity and relative humidity range for DSV-4 (R^2 =0.74). This suggests the requirement of higher thermal energy and atmospheric demand for profuse leaf and stem growth. The models have R^2 values between 0.76 and 0.90.

Primordial initiation stage

Leaf growth:

Leaf growth in this stage has leaf dry weight at 30 DAS and afternoon vapour pressure as model parameters for M35-1 (R^2= 0.71) and DSV-5 (R^2= 0.35), and leaf dry weight at 30 DAS alone for DSV-4 ($R^2 = 0.72$).

For stem growth the model parameters are leaf dry weight at 30 DAS and afternoon vapour pressure for M35-1 ($R^2 = 0.72$), stem dry weight at 30 DAS and afternoon vapour pressure for DSV-5 (R^2 =0.46), and afternoon vapour pressure alone for DSV-4 ($R^2 = 0.56$)

In this stage, the atmospheric hygric factor plays a crucial role in modeling the crop growth.

Table 4.1a: Regression models developed for predicting various growth parameters in *rabi* sorghum Cv. M35-1

DAS	Component	Model	R^2	SEE
0-30	Leaf	Y= 1.41(TX30)+1.35(EP30)-48.3	0.95	0.79
	Stem	Y= 0.124(RH230)+8.8	0.76	0.6
31-45	Leaf	Y= - 3.40(VP245)+9.93(L030)+36.5	0.84	11
	Stem	Y= - 0.800(VP245)+3.76(L030)+7.9	0.85	4.7
46-60	Leaf	Y= 0.911(RH160)+1.45(TR60)+1.85(S045)-83.2	0.94	8.9
	Stem	Y= 18.4(TR60)+6.34(S045)-281.6	0.80	72.3
61-75	Leaf	Y= 3.40(TX75)-0.558(CBSS75)+0.155(L060)-30.7	0.94	6.7
	Earhead	Y= 4.83(RH175)-336.9	0.72	19.4
76-90	Leaf	Y= 15.5(EP90)-88.7	0.71	9.6
	Stem	Y= - 3.41(VP190)+1.10(CBSS90)-94.4	0.71	28.3
	Earhead	Y= 2.38(VP290)+0.929(EH75)-31.7	0.89	11.8

Table 4.1b: Regression models developed for predicting various growth parameters in *rabi* sorghum Cv. DSV-5

DAS	Component	Model	R^2	SEE
0-30	Leaf	Y= 1.48(TX30)-0.047(RH230)+0.053(EP30)-39.8	0.87	1.2
	Stem	Y= -0.085(RH230)+0.097(RHR30)+3.9	0.88	0.45
31-45	Leaf	Y= 2.79(VP245)+0.682(L030)-31.3	0.59	13.4
	Stem	Y= 2.75(VP245)-3.90(S030)-29.4	0.68	6.2
46-60	Leaf	Y= 0.889(TN60)+2.60(TR60)+1.89(S045)-42.3	0.86	13.8
	Stem	Y= 0.131(TR60)+4.89(S045)+9.9	0.96	11.6
61-75	Leaf	Y= -0.449(RHR75)-0.345(CBSS75)+68.0	0.86	6.2
	Stem	Y= 5.83(VP275)+0.593(S060)-37.5	0.95	13.4
	Earhead	Y= 3.01(TX75)+0.129(S060)-82.0	0.92	3.5
76-90	Leaf	Y= 3.37(EP90)-0.239(L075)-13.7	0.92	5.3
	Stem	Y= -1.65(RHR90)-2.33(GDD90)+357.2	0.85	18.5
	Earhead	Y=- 0.945(TN90)+0.906(RHR90)-1.28(GDD90)+175.5	0.91	16.5

Table 4.1c: Regression models developed for predicting various growth parameters in *rabi* sorghum Cv. DSV-4

DAS	Component	Model	R^2	SEE
0-30	Leaf	Y= 1.58(TX30)+0.742(EP30)-49.2	0.97	0.59
	Stem	Y= 0.210(TX30)-0.046(RH230)+0.09(RHR30)- 4.8	0.86	0.51
31-45	Leaf	Y= 7.17(L030)-5.07	0.78	10.7
	Stem	Y= 2.03(VP245)-23.3	0.75	4.7
46-60	Leaf	Y= 0.532(TN60)+1.99(TR60)+2.20(S045)-34.0	0.98	4
	Stem	Y= 2.24(RH160)+1.87(TR60)+1.82(L045)-186.4	0.98	9.9
61-75	Leaf	Y= 0.184(S060)-1.84	0.80	6.5
	Stem	Y= 1.98(S060)-1.52(L060)+11.6	0.95	14
	Earhead	Y= - 8.21(TN75)+6.05(BSS75)+80.4	0.73	25.4
76-90	Leaf	Y= 4.98(VP245)-0.547(RHR90)-66.2	0.86	12.7
	Stem	Y= - 13.9(TN90)+159.9	0.80	20.6
	Earhead	Y= - 10.74(VP145)+0.713(RHR90)+0.059(CBSS90)+101.3	0.70	24.6

Flag leaf initiation:

Models for leaf growth have stem dry weight at 45 DAS, morning relative humidity and temperature range as model parameters for M35-1 (R^2=0.88). Stem dry weight at 45 DAS, minimum temperature and temperature range are the model parameter for both DSV-5 (R^2= 0.74) and DSV-4 (R^2= 0.96).

Stem growth at this stage can be modeled by stem dry weight at 45 DAS and temperature range for M35-1 (R^2=0.64) and for DSV-5 (R^2 =0.92), and by leaf dry weight at 45 DAS, morning relative humidity and temperature range for DSV-4 (R^2 =0.96). Thus, the weather situation during night/early morning is of importance in this period for quantification of the crop growth parameters.

Flowering:

Leaf growth models in this period have leaf dry weight at 60 DAS, maximum temperature and cumulative sunshine duration (in 61-75 DAS) as model parameters for M35-1 cultivator (R^2=0.88), relative humidity range and cumulative sunshine duration (in 61-75 DAS) for DSV-5 (R^2=0.88), and stem dry weight at 60 DAS for DSV-4 (R^2=0.64).

Stem growth in M35-1 could not be modeled in view of poor correlations. The model parameters for stem growth are, stem dry weight at 60 DAS and afternoon vapour pressure for DSV-5 (R^2=0.90) and both stem dry weight and leaf dry weight at 60 DAS for DSV-4 (R^2=0.90)

In case of earhead growth during 61-75 DAS, the model parameters are morning relative humidity for M35-1 (R^2=0.54) stem dry weight at 60 DAS and maximum temperature for DSV-5 (R^2=0.84) and sunshine duration and minimum temperature for DSV-4 (R^2=0.53).

Absence of dry matter component as a model parameter in the leaf growth model for DSV-5 makes it more weather sensitive and presence of only dry matter component as model parameter in the models of leaf growth and stem growth in DSV-4 genotype present it as weather insensitive or less weather sensitive.

In view of absence of dry matter component as model parameter in the models for M35-1 and DSV-4, they become susceptible to weather changes in this stage.

Grain filling:

Leaf growth model in this stage has evaporation as the sole model parameter for M35-1(R^2=0.50), leaf dry weight at 75 DAS and evaporation for DSV-5 (R^2=0.84), and afternoon vapour pressure and relative humidity range for DSV-4 (R^2=0.74).

Stem growth is modeled by morning vapour pressure and cumulative sunshine duration for M35-1 (R^2=0.50), relative humidity range and GDD for DSV-5 (R^2=0.72), and only minimum temperature for DSV-4 (R^2=0.64).

The models for earhead growth in this period contain earhead dry weight at 75 DAS and afternoon vapour pressure for M35-1 (R^2=0.79), minimum temperature, relative humidity range and GDD for DSV-5 (R^2=0.82), and afternoon vapour pressure, relative humidity range and cumulative sunshine duration for DSV-4 (R^2=0.49) as model parameters.

Inferences:

Thus, we find that: In case of M35-1, the models comprised meteorological variables alone as model parameters on three occasions, viz., (1) Earhead growth during 61-75 DAS, (2) Leaf growth and (3) stem growth during 76-90 DAS.

In case of DSV-5, the model parameters were only meteorological variables on three occasions, namely, (1) leaf growth at 61-75 DAS, (2) stem growth and (3) earhead during 76-90 DAS.

Since the DSV-5 earhead growth model during 76-90, is purely weather responsive, the genotype becomes weather sensitive and hence risky, compared to M35-1.

In case of the cultivar DSV-4, five models possess variables only of meteorological parameters. They are, (1) stem growth at 31-45 DAS, (2) earhead growth at 61-75 DAS, (3) leaf growth, (4) stem growth and (5) earhead growth at 76-90 DAS. Thus, this genotype is exceedingly weather sensitive.

In view of the above responses, M35-1 is agrometeorologically identified as the least risky genotype for growing in the north Karnataka.

Simulation modeling of *rabi* sorghum

WOFOST crop simulation model was adopted for this purpose to analyse the response of the model to the popular genotype M35-1.

Calibration of WOFOST crop simulation model for *rabi* sorghum

Iterative process was adopted to calibrate the WOFOST crop simulation model, by making modifications in the genetic coefficients in the model to simulate the *rabi* sorghum yields for the dominant cultivar M35-1 and also its phenology. The crop genetic file of the model was used for calibration purpose, and the modified values are presented in Table 4.2.

Table 4.2 Modification in values of model parameters in calibration of WOFOST model for *rabi* sorghum CV. M35-1

Parameter	Value	Description
** emergence		
TSUMEM	= 111.6	Temperature sum from sowing to emergence [cel d]
** phenology		
TSUM1	= 786.7	Temperature sum from emergence to flowering
TSUM2	= 427.6	Temperature sum from anthesis to maturity
** conversion of assimilates into biomass		
CVL	= 0.310	Efficiency of conversion into leaves [kg kg-1]
CVO	= 0.180	Efficiency of conversion into storage org. [kg kg-1]
CVR	= 0.120	Efficiency of conversion into roots [kg kg-1]
CVS	= 0.390	Efficiency of conversion into stems [kg kg-1

Validation of results of WOFOST model

The model was run with the modified genetic coefficients for the dominant cultivar M35-1, and validated for three years' experiment data. The results are given in Table 4.3 and Table 4.4.

Table 4.3 Results of WOFOST model on sorghum phenology

Date of sowing	Flowering (Days after sowing)			Physiological maturity (Days after sowing)		
	Obs	Pred	% Error	Obs	Pred	% Error
15.09.2009	70	66	-5.7	110	108	-1.8
06.10.2009	67	62	-7.5	106	102	-3.8
16.10.2009	65	60	-7.7	101	97	-3.9

Note: Obs = Observed, Pred = Predicted,
% Error = ((Predicted – Observed) / Observed)* 100

Table 4.4 Validation of results of WOFOST model for *rabi* sorghum yield

Date of sowing	Revision in crop file parameters in model Grain Yield (kg ha^{-1})		
	Obs	Pred	% Error
21.09.2007	1312	1061	-19.1
01.10.2007	1906	896	-53.0
22.10.2007	1090	626	-42.6
19.09.2008	314	1136	261.8
06.10.2008	720	940	30.6
15.09.2009	1399	1458	4.2
06.10.2009	1226	1551	26.5
16.10.2009	1787	1475	-17.4

It is noticed from Tables 4.2 to 4.4 that in case of early sowing of the crop on 15th September 2009, the model with the revised coefficients could evaluate both the flowering time and maturity within a tolerable limit of four days and two days respectively. The model provided good yield estimation in case of early sown crop of September 15, 2009 with only 4.2 % error. The percent error of the model in the estimation of anthesis is between -5.7 to -7.7, physiological maturity is -1.8 to -3.9 and in case of grain yield is between -17.5 to 26.5. Therefore, the yield estimations for the popular *rabi* sorghum variety M35-1 can be termed as moderately reasonable.

5. Effect of Extreme and Unseasonal Weather on Yield of *rabi* Sorghum

Different extreme / unseasonal weather situations have occurred in almost every year during the 21st Century. We give two examples of the effect of such events on *rabi* sorghum crop – 1) Occurrence of rainfall in mid-December and 2) Prevalence of extremely low minimum temperatures during December-January.

Role of occurrence of rainfall in mid-December

Weather parameters during Primordial Initiation (PI) stage were identified as the most important in determining the grain yield of *rabi* sorghum genotype M35-1. Sunshine duration and diurnal temperature range showed negative association with grain yield, whereas rainfall and relative humidity showed positive association. On the other hand, rainfall during flowering stage indicated adverse effect on the yield.

Regression models for estimating sorghum grain yield were been developed using relative humidity and temperature range in primordial initiation stage. Graphical presentation of the relation is shown in Figs 5.1 and 5.2

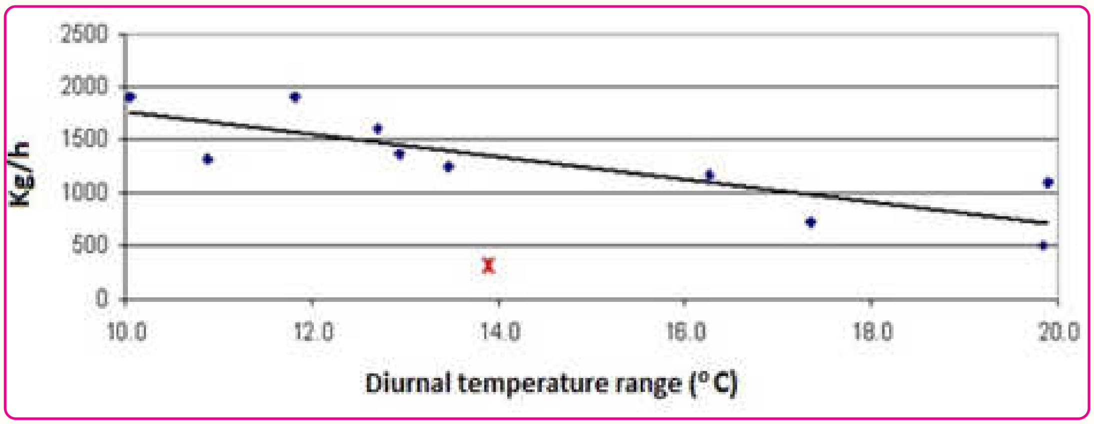


Fig 5.1. Influence of diurnal temperature range during primordial initiation stage on grain yield of *rabi* sorghum

Model 1: Y= -100.8(TR) + 2652.7 (R^2 = 0.43)

Where, Y = Grain yield of *rabi* sorghum (Kg/ha)

TR= Temperature range in primordial initiation stage (^{o}C)

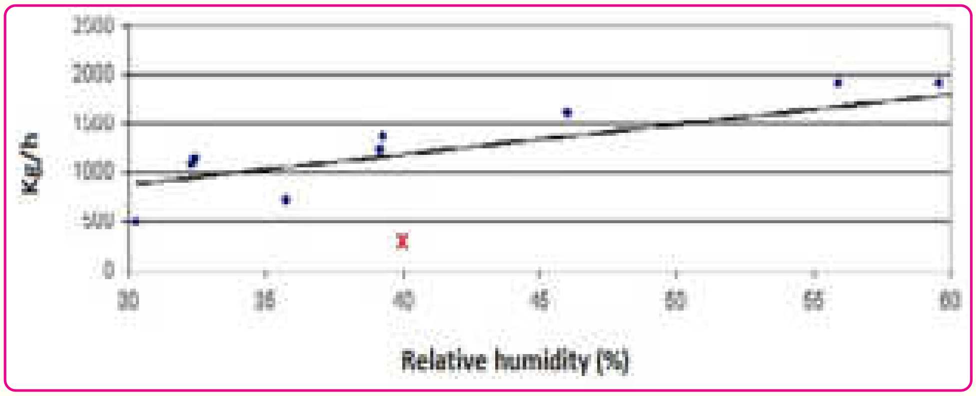


Fig 5.2. Influence of afternoon relative humidity during primordial initiation stage on grain yield of *rabi* sorghum

Model 2: Y= 31.92 (RH2) – 169.41 (R^2 = 0.47)

Where, Y = Grain yield of *rabi* sorghum (Kg/ha)

RH2 = Afternoon relative humidity in primordial initiation stage (%)

A multiple regression model was developed by using both temperature range and afternoon relative humidity during primordial initiation stage as dependent variables.

Model 3: Y= 22.22(RH2) – 36.69(TR) + 775.8 (R^2 = 0.49)

The yield of sorghum crop in the first growing environment (DOS= 19 Sept, 2009) was only 314 kg/ha (**X** Mark in Figs 5.1 and 5.2). Even though favourable meteorological conditions were encountered during the primordial initiation stage, the yield was very low (Fig 5.1 and Fig 5.2). In this case, the negative association of rainfall in flowering/grainfilling stage was considered, and the conditions for low yield were satisfied. The reduction in yield levels brought about by occurrence of rainfall in flowering./grain filling stages were analyzed and are given in Table 5.1.

Table 5.1: Role of rainfall during flowering and grain filling stages on grain yield of *rabi* sorghum

Model No.	Observed yield: 314 kg/ha at RH2=40% and TR=13.9 °C			Remarks
	Predicted yield (Kg/ha)	Deviation fromobserved (Kg/ha)	Per cent Deviation	
Model 1	1252	937.4	74.9	This deviation is ascribed to the negative influence of rainfall in flowering and grain filling stages
Model 2	1107	793.2	71.6	
Model 3	1154	840.4	72.8	

It is thus inferred that the negative influence of rainfall during flowering and grain filling stages can reduce yield by as much as 70 to 75 per cent, even when conditions in primordial initiation stage are favorable. In order to ascertain how frequently this can occur, the weekly rainfall and probability occurrence of the received amount in the respective standard weeks in northern dry zone of Karnataka is presented in Table 5.2.

Table 5.2: Probability of rainfall occurrence in flowering/grainfilling stage of *rabi* sorghum

Standard Week No.	Normal rainfall (mm)	Rainfall during 2009 (mm)	Probability of occurrence
45	7.8	9.6	20-25 %
46	5.1	19.6	5-10 %
47	2.8	14.8	5-10 %

It is clear that rainfall does not occur during all the three weeks in most of the years as indicated by the rainfall probabilities in week numbers 46 and 47. Since the crop received rainfall in critical phase of its negative impact, the models developed have shown limited application. Rainfall during the critical stage cannot be taken as an independent variable because, in most years the region does not receive rainfall in this period. So, we need to update the yield forecast after December.

Role of extremely low minimum temperature in December-January

At least one extreme meteorological event was experienced during the past decade, making it more and more risky for agriculture to be sustainable. During the *rabi* season of 2010-11, minimum temperature of less than 10^{O}C prevailed during December-January. Farmers who were hoping for good yield of sorghum were surprised to get higher wheat yield instead, and the sorghum yields were reduced. We can see in the following tables (5.3 and 5.4) and figures (5.3 and 5.4) the temperature profiles during winter months of 2009-10 and 2010-11 along with corresponding *rabi* sorghum yield.

Table 5.3 : Minimum temperature at RARS, Bijapur during seed filling and seed development stages of sorghum during 2009-10 and 2010-11

Month	Bijapur	
	2009-10	2010-11
December	14.3	12.9
January	14.5	11.3
February	16.7	15.2

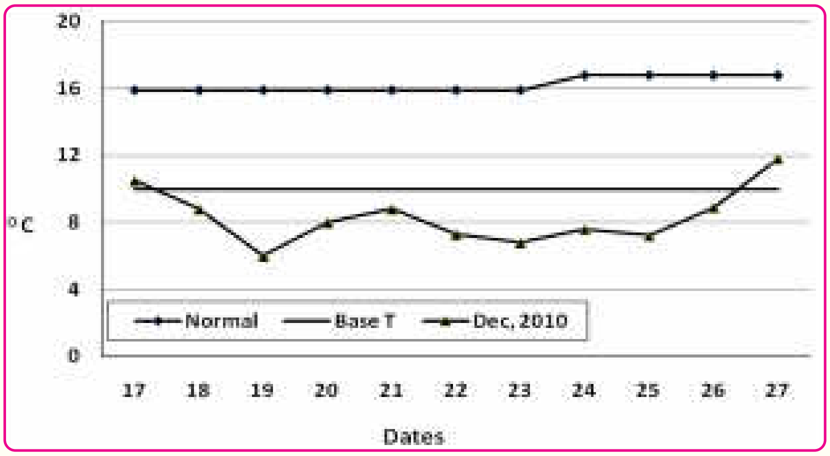


Fig 5.3 : Daily minimum temperature during December 2009

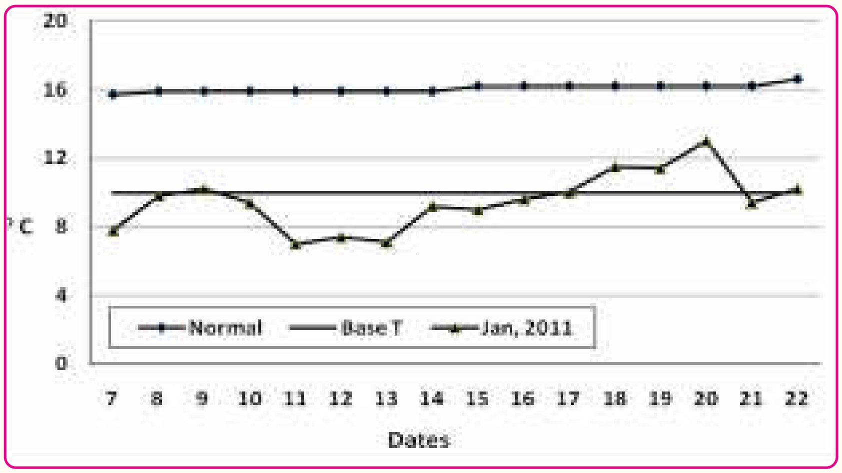


Fig 5.4 : Daily minimum temperature during January 2011

Mean minimum temperature during December 2010 was lower by 1.4 ^{O}C compared to December 2009 and lower by 3.2 ^{O}C during January 2011 compared to January 2010 (Table 5.3). The minimum temperature was below base temperature of 10 ^{O}C for nine consecutive days in December 2010 and seven consecutive days during January 2011. This is considerable duration to reduce physiological activity and thereby reduced yield of sorghum crop.

Yield of *rabi* sorghum crop at Bijapur station and in northern dry zone of Karnataka obtained from AICRP on Sorghum, RARS, Bijapur is presented in Table 5.4. The impact of low minimum temperature below the based temperature of 10 ^{O}C can be clearly noticed.

Table 5.4: *Rabi* sorghum yield during 2009-10 and 2010-11

Location	Grain yield of *rabi* Sorghum (kg/ha)		
	2009-10	2010-11	% Reduction
Northern Dry Zone of Karnataka	1896	1538	18.90
Bijapur	1766	1267	28.25

Thus the extremely low minimum temperature for more than a week during the reproductive period of *rabi* sorghum reduced the yield considerably. It is clear that extreme events that prevail in the crop growing season have considerable impact on *rabi* sorghum yield. In the event of such cases what measures farmers need to take up to alleviate the adverse effect of low temperatures is required to be understood. Thus, it is necessary to develop technologies to withstand or reduce the adverse effects of unfavourable weather.

6. Summary

The report presented the climate normals and climate variability patterns, and identified sinusoidal patterns of rainfall in the region.

Within season variations in rainfall, temperature and relative humidity were also presented, and the following periods as having higher weather based risks are identified.

- Maximum temperature exhibits large variations during SMW 40,50,02 and 03.
- Extremes of minimum temperature are noticed in SMW 43,46 to 52 and 01.
- Out of the series of weeks from SMW 46 to SMW 01, the weeks SMW 46-48 are governed by a rise in minimum temperature, whereas SMW 50 to SMW 01 are governed by a fall in minimum temperature.
- Large extremes in morning relative humidity are noticed during 49-52 SMW.
- Extreme negative deviation of afternoon relative humidity during 38- 47 SMW and 1 and 2 SMW are observed: These periods may enhance risk for the prevailing crops.

The quantification of sorghum yield through correlation and regression analysis with meteorological variables indicated that the same variables were generally responsible in determining the yield. However, the timing of the association was seen to be more important. Early or delayed response by even one week to the same variables would affect the final yield. Individual grain yield models have been developed for different genotypes.

The procedures and results presented in this report can be used for further improvement in the methodologies and adaptations.

Genetic coefficients were developed for the WOFOST simulation model. They were used to simulate phenology and grain yield of *rabi* sorghum genotype M35-1. The results showed simulation of phenology and yield predictions with reasonable accuracy.

Extremely low minimum temperature for more than a week during the reproductive period of *rabi* sorghum reduced the yield considerably. It is clear that extreme events that prevail in the crop growing season have considerable impact on *rabi* sorghum yield. In the event of such cases the measures need to be taken up to alleviate the adverse effect of low temperatures is required to be properly designed. Thus, it is necessary to develop technologies to withstand or reduce the adverse effects of unfavourable weather.

Role of rainfall of even 20-30 mm in first fortnight of December is identified as harmful, and minimum temperature less than the base temperature of 10.0 ^{o}C for more than one week in the months of December and January would reduce the yield considerably.

The reason behind the popularity and sustainability of the variety M35-1 was identified as the lower dependability of earhead growth to weather variables than on the previous stage biomass itself. The genetic role may need further attention.

REFERENCES

Anonymous, (1996-2010). Annual Reports of AICRP on Agrometeorology, Bijapur Center.

DES, 2012. Directorate of Economics and Statistics. New Dehi, India: Ministry of Agricuture, Government of India.

GOI. 2007. Agriculture statistics at a glance. Directorate of Economics and Statistics. New Dehi, India: Ministry of Agricuture, Government of India.

Hosamani.M.M and Chittapur.B.M. 1997. Sorghum production technologies.Publishers:Mrs. Sarasijakshi M. Hosmani.

Rupa Kumar K, Krishna Kumar K, Pant GB, Srinivasan G (2002).Climate change-The Indian scenario. In: Background paper prepared by FICCI, International conference on Science and Technology Capacity Building on Climate change, October 20-22, New Delhi,5-17


Drought affected crop
Healthy crop