An Analysis of Weather and Wheat Crop Development in Lower Sindh (Tandojam) (2005-2010)

by

Muhammad Ayaz
Dr. Khalid M. Malik
Kazi Khalid

National Agromet Centre
Pakistan Meteorological Department
PitrasBukhari Road, Sector H-8/2
Islamabad, Pakistan

Summary

The present study has been carried out to investigate the impact of day to day changes in the weather parameters like rainfall, air temperature; soil temperature and soil moisture on plant growth and development during each phenological stage and on final yield of the crop. For this purpose both Meteorological and phenological observations along with soil data have been investigated at different phonological stages of wheat crop, cultivated in the field of Plant Physiology Section of Agricultural Research Institute Tandojam (Lower Sindh) in the Rabi season during the period 2005-07 to 2010-11. The crops cultivated during this period have been investigated and analyzed thoroughly with respect to their variety and yield obtained. The impact of abnormal rise in temperature particularly during grain formation stages due to any climatic variability or late sowing has also been investigated. Variations in fertilizer and seed intake, weeds removing operations and supply of irrigation water and their impact on crop growth, development and production have also been studied. The crop, on average, accumulated 2349 heat units in 122 days during its life cycle from sowing to full maturity. Water requirement was made through flood irrigation onwards from early growth up to completion of wax maturity stage. The yield obtained was satisfactory/near to normal yield during the years 2006-07 and 2007-08; and bumper crop, normal to above normal yield, was obtained for the years 2008-09 to 2010-11. Whereas below normal yield was obtained in 2005-06.The variation in the yield was due to the combined effect of meteorological and non-meteorological factors. This study is based upon limited data years of each individual wheat cultivar. Therefore the study will be much fruitful in future to narrow the gap between present yield obtained and potential yield of these varieties, being cultivated in Tandojam and other wheat growing areas of lower Sindh.

TABLE OF CONTENTS

Chapter 1

Introduction

This study is based upon field observations of wheat crop by Regional Agromet Center Tandojam, cultivated in the experimental field of Plant Physiological section of ARI Tandojam, located in the north- east at about 50 meter of Agromet Observatory of RAMC Tandojam, during the period 200-01 to 2010-11. The study permits the wheat varieties TD-1and TJ-83 recommended by Sindh Agriculture Department for lower Sindh. The study will provide a base to estimate the optimum ranges of various meteorological parameters for getting highest yield of the particular crop variety grown under varying weather conditions.

1.1. Geographical Description and Climate of Pakistan and Lower Sindh (Study Area)

Pakistan lies in south west Asia with lofty Pamir Platue to the north and the vast Arabian sea to the south. The tropic of Cancer passes immediately south of the country. Exact location of the country is 24°-37°N latitude and 61°-76°E longitude. Highest mountain ranges of Himalaya's lies in the extreme north with height reaches more than 8000 m a.m.s.l. Himalayas play an important role in the development and tracking of monsoon weather systems during summer over South Asia including Pakistan. Himalayas also act as a barrier against the cold Siberian winds to enter Pakistan and other countries of South Asia during winter. The Suleiman and Kherthar ranges in the south of Pakistan have comparatively lower heights (750-3300m) and do not play any significant role in weather variation of the country like Himalayas in the north. Between the northern high mountainous and sub-mountainous region and southern hills, there is a vast agriculture plain, also called great Indus plain (Shamshad, 1988).

The Indus plain in combination with the Gangatic plain of India, also called the Indo-Gangatic plain, was very famous in ancient times for the production of Cotton and wheat and the center of ancient Indus civilization.

Pakistan has a variable climate, ranging from arid (0-10inches/0-254mm annual rainfall) in the south to humid (40-80inches per year), sub-humid (20-40inches per year) and semi-arid (10-20inches per year) in the north. The river Indus that originates in the north with its tributaries irrigates the great plain of the country (Shamshad, 1988).

The area to the left of Indus is much affected by the neighboring arid and hot Rajasthan desert. The agriculture in the major portion of upper half of the country which is semi arid depends upon flood irrigation besides considerable intake of rainfall water also available due to monsoon weather systems that enter into the atmosphere of the country, mostly from northeast in the Province of Punjab and adjoining areas in summer. Winter rains occur due to westerly waves that penetrate into the atmosphere of Pakistan from the northwest. A narrow patch in the upper half of the country is sub-humid to humid, comprising of the mountainous to sub mountainous areas of Punjab and adjoining areas of Khyber Pakhtoonkhawa, where heavy precipitation occurs both in summer and winter and agriculture is carried out without canal irrigation (Chaudhry and Rasul, 2004)

The climate of lower half including agricultural plains of southern Punjab, Sindh and Baluchistan have mostly arid climate, where annual rainfall is lower than potential evapotranspiration and crop production is not possible without irrigation. Most of the rainfall is received during summer monsoon period and meager rain occurs due to rare westerly waves that pass across lower parts of the country. The lower parts of Sindh are slightly cooler and more humid than upper parts due to Arabian Sea.

Regional Agromet Center (RAMC) is situated in the Plant Physiological Section of Agricultural Research Center Tandojam, located in the lower parts of Sindh, 20 km way from Hyderabad city on Mirpurkhas- Hyderabad highway. The latitude and longitude of RAMC Tandojam are 38.33º and 25.25º respectively. Total annual rainfall in lower Sindh ranges 145-155 mm (145 mm in Tandojam), 75% of this is received during summer monsoon period July-Sep) and meager rain occurs due to rare westerly waves that pass across lower parts of the country in winter. Temperature ranges cool to cold in winter and hot to very hot during summer. More detail about the climate of Tandojam is located in the following Figures (1.1 to 1.3), which clearly indicates that highest amount of rainfall occurs during Monsoon / Kharif season in the month of August, followed by July. Whereas lowest amount occurs during Rabi season in January, followed by December and November. In Rabi season highest amount of rain occurs in March. Day time mean maximum and mean minimum gradually decrease from November up to January and then increase up to March (PMD, 2005).

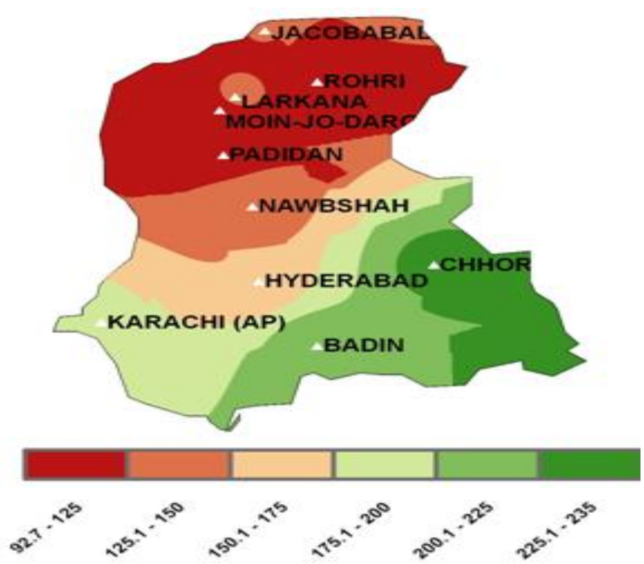


Figure 1.1: Mean Annual Rainfall (mm) of Sindh

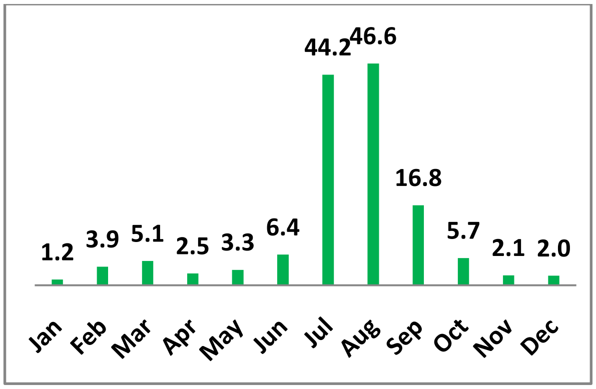


Figure 1.2: Monthly Mean Annual Rainfall (mm) of Tandojam

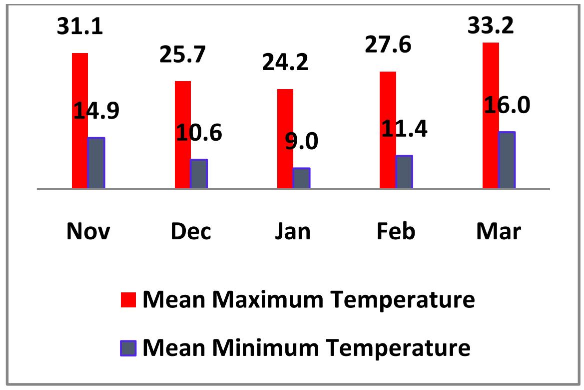


Figure 1.3: Mean daily Maximum and Minimum Temperature (ºC) of Tandojam during Rabi Season.

1.2. Review of Agriculture Production Including Wheat Crop in Pakistan

Pakistan is an agrarian country whose both population and economy depends upon agriculture. Firstly it provides food and fibbers for local industry, secondly it is the main source of our exports earnings and lastly it provides market for industrial commodities. Agriculture shares about 20-25% to country's Gross Domestic Product (GDP). About 68 % of the rural population living depends on agriculture. Within the agricultural sector, the share from crop production is about 52 % while livestock contributes about 44 %. Therefore any change in agricultural production has sudden impact over the population of Pakistan. Thus fastest agricultural growth can maintain the speed of industrial and consequently economic growth (Economic Survey of Pakistan, 2009).

1.3. Wheat

Wheat flour is the staple food for most of Pakistanis. Wheat consumption in our country is estimated at around 124 kg per person per year. This is among the highest over the globe [5].

Keeping above facts in mind; importance of wheat crop is unquestionable for us. Therefore year to year variation in the total yield of wheat due to several factors including climate and weather variations directly affects the economy and social balance of the country.

During the last season of 2010-11, wheat was cultivated on 8,805 hectares, showing a decrease of 3.6 percent over last year's area of 9,132,000 hectares. However, bumper wheat crop of 24.2million tons has obtained with 3.9 percent increase over the last year's crop of 23.3 million tons. Production of wheat increased due to in time fertilizer intake and effective rainfall during the crop life, besides other factors (Agriculture times, 2011).

Wheat is a Rabi crop that is grown in the winter season. In Pakistan Sowing of wheat takes place in October to December and harvesting during the month of March to May. In Sindh the crop sowing period is November-December and harvesting period is March-April. Due to climate variation in upper and lower Sindh sowing and harvesting of wheat starts 10 to 15 days earlier in lower Sindh than upper parts. Seed depth for wheat crop in Sindh is 5cm and row spacing is 23cm (Khoso, 1977). The growth period of wheat plant is temperature dependant. A fact which not only limits the choice of the cultivars to early maturing types, which grow rapidly, but also influences the geographical distribution of the crop. The wheat season becomes shorter from north to south in correspondence with the duration of winter, which decreases in the same direction. Wheat crop matures in 140 -160 days in northern region, 120–140 days in the central region and 100–120 days in the southern warmer parts of the country including Sindh (Rasul, 1993).

The fertile land of Sindh occupies southeastern parts of the country, which is famous for the production of cotton, wheat, rice, sugarcane and orchards like mango, banana and seasonal vegetables.

Sindh can be compared with Egypt; both have fertile alluvium deposited by the rivers Indus and Nile, respectively. This is the main reason for the domination of fertile land of Sindh in per hector yield among all the agricultural plains of the country (Panhwar,2005).

The province of Sindh ranks second in wheat production. Most of the lands devoted to wheat cultivation in the lower Indus Plains are located in the irrigated districts of Nawabshah, Hyderabad, Sukkur, and Tharparkar Kharipur Districts.

Crop water requirement of wheat in Pakistan varies from 271mm to 514mm. maximum amount is required to the crop in Sindh and adjoining areas due to hot and arid climate of the region (Kazmi,2009). As discussed above, the total annual rainfall in lower Sindh including Tandojam region is much lower than the wheat crop water demand. Therefore it is evident that wheat crop growth is mostly dependent upon irrigated water of Indus canal system in the lower Sindh.

This study was conducted during the period 2000-2011 in the Experimental field of plant physiology section of Sindh Agriculture Research Institute Tandojam, located in the north- east at about 50 meter of Agromet Observatory of R.A.M.C Tandojam. The study permits the wheat varieties TD-1, TJ-83, Abadgar-93, Mamool-2002 and Anmol-91 recommended by Sindh Agriculture Department for lower Sindh which were cultivated during the mentioned period. The study will provide a base to estimate the optimum ranges of various meteorological parameters for getting highest yield of the particular crop variety grown under different Agro- climatic conditions.

1.4. Scope and Aim of the Study

Wheat, being the single staple diet, is the most important cereal crop in Pakistan and is cultivated almost in every part of Pakistan. Since per acre yield has been increased since 1947 gradually with the adaptation of high yield cultivars, increasing use of nitrogen and phosphorus fertilizers, increasing the length of canal irrigation network along with ideal soil texture of Indus basin for the growth of wheat crop, but per acre yield being obtained in the country is almost half of the yield of major wheat producing countries and is one fourth of the potential yield of these cultivars.

It is difficult, though not impossible to apply all the available means regarding research activities and other resources to enhance the annual yield by coping with all the negative factors that reduce the annual crop production. This research study is an attempt to analyze the impact of variations in weather and other important factors like time of sowing, the amount of seed added to the field, fertilizer doze, in time removal of weeds, year to year variations in irrigation water and so on. In spite of very limited data available this study investigates all important factors that reduce the crop's yield in the area of lower Sindh to reduce the negative impacts for obtaining higher yields in future. Further in this study it is tried to set a mechanism for prediction of crop yield as well as harvesting dates.

Chapter 2

Materials and Method

Materials and Method

This study is based upon field observations of different recommended varieties of wheat crop planted in the in the Experimental field of plant physiology section of Sindh Agriculture Research Institute Tandojam in lower Sindh.

For this purpose both meteorological and crop data were recorded during the crop season. In order to compile the data of each Phenological stage; careful, precise and timely recording of the following parameters were undertaken at 0300, 0900 and 1200 (UTC) as routine practice.

Table 2.1: Observed Meteorological Parameters

•

1	Air temperature (°C)
2	Maximum and Minimum Temperature (°C)
3	Soil Temperature (°C)
4	Relative Humidity (%)
5	Precipitation (mm)
7	Bright Sunshine Hours
8	Wind speed (Km/Hr) &Wind Direction
9	Soil Moisture (%)

Weather parameters and crop data including Phenological and soil moisture/temperature observations at different depths, were observed and recorded according to World Meteorological Organization (WMO) and Food and Agriculture Organization (FAO) standards.

2.1 Phenological Observations

plant growth and development and any response of plant to any stress and impact of any application like irrigation, rainfall, fertilizer or weedicides operation is best understood by plant varying response at different phenological phases [14].

2.1.1Phenological Stages of Wheat Crop

Growth period of wheat crop consists of the phenological stages/phases.

Germination

In this phase embryo appears forming the cotyledons. These cotyledons then become green on reaching surface of the soil. In this phase the embryo has pushed out of the grain tegument.

Emergence

Actually it is the first phase of wheat plant. In case of cereal like wheat in this phase first leaves form.

Third Leaf

This phase is distinguished by the formation of third leaf. The phase tells us that wheat plant is fully established now.

Tillering

In this phase branches start to form on main stem. The plant has one main stem and several secondary stems or tillers.

Shooting (Stem Extension)

This phase is distinguished by the clear development of the first stem node at 1 – 2 cm above the soil and hidden under the leaf sheath. Sometimes it is difficult to see the node. However, it can be felt by pressing the stem at about that height with fingers.

Heading (Earing)

This phase is established when half of the head comes out of the upper leaf of the main stem.

Flowering

This phase starts with the appearance of the first flowers on the top of main stem.

Milk Maturity

This phase starts during heading stage. The grain in this stage is green and a milky white liquid comes out by pressing.

Wax (Dough) Maturity

Grain colour is yellow at this stage. The grains, however, are not very hard. Their contents are like wax. At this stage the moment of nutrients grain from different parts of plant stops.

Full Maturity

The grains are hard at this stage and cannot be cut by fingernails. Wheat plant is now completely dry. Hot and dry weather favors at this stage (Fowler,2002).

2.1.2Phenological Observations in the Field Selected for Wheat Crop at A.R.I Tandojam

Generally the field selected for Phenological observations should be of one hector size but the field selected for observations for these crops was one acre and it was divided into 4 replications. Over all 10 plants were selected from each replication. These plants were tagged in a row in each replication. Thus Phenological observations were recorded on 40 plants and continued throughout the period on the same plants.

Phenological phases were particularly identified from the observed data. Total number of plants in a particular Phenological phase at the same time was observed from each replication on every Monday, Wednesday and Saturday. These observations were recorded on the prescribed Performa. When 10% of the selected plants were in certain phase, that particular phase was considered to be started. If 50% of the selected plants displayed a certain phase, that phase was considered to be in full swing. Similarly 75% occurrence of a certain phase displayed by the selected plants was considered as completion of that particular phase and next Phenological phase observations were started at their proper time. Thus next Phenological stage is not bound to appear after the completion of first one. It has been observed that at a time two Phenological phases may also exist.

2.2Analysis of the Impact of different Meteorological Parameters on Crop Growth and Development

2.2.1 Rainfall Profile of the Crop

Rainfall is one of the most important factors that affect annual wheat production in Pakistan. Annual variation in rain/snowfall over hills and plain areas of the country also causes up down in proper supply of canal irrigation water.

In time or effective rainfall i.e. before sowing and from shooting to grain formation stage is necessary input in yield production, but with suitable intervals in required amount of the Phenological phase before full maturity contributes to normal or above normal yield of the crop as continuous rainy and moist atmosphere does not suit normal growth to wheat crop. In the same way, rain after sowing and before germination and at the time of full maturity negatively affect crop growth and ultimately reduce the yield.

Tandojam and its surrounding areas of lower Sindh get meager rain during Rabi season as winter rains bearing westerly waves rarely pass over lower Sindh. Therefore wheat crop is mainly grown under flood irrigation from Indus canal network. But irrigation water becomes deficient sometime in February/March and rain during such shortages positively promotes crop growth. In addition irrigated water rainfall also provides clean environmental conditions to support optimum photoperiodic activity for better biomass and grain yield (Rasul, 1993).

2.2.2 Rainfall during Rabi Season 2005-06

Weather remained dry up to the month of March. In the start of 2nd decade of March (13th and 14th March), 50mm rain was recorded during full maturity stage, which badly damaged/affected the crop.

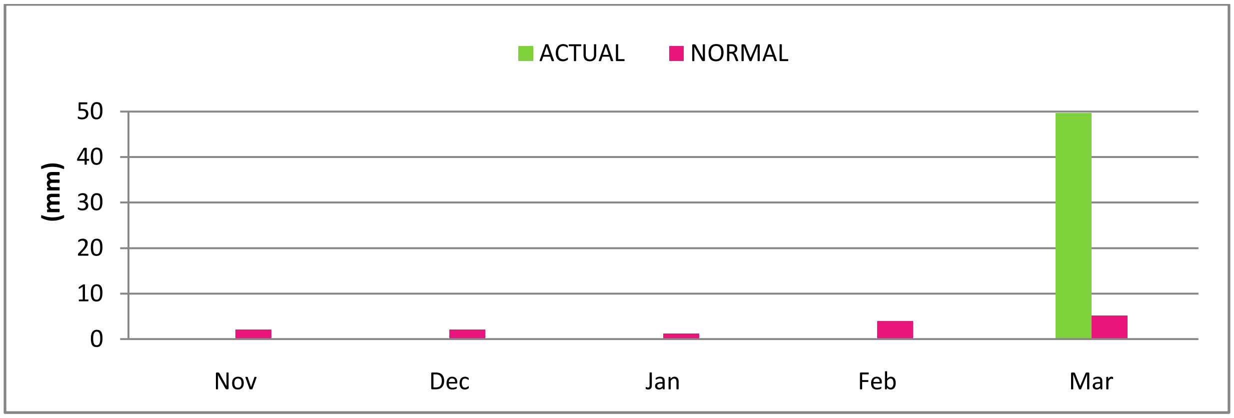


Figure 2.1: Rainfall during 2005-06

2.2.3Rainfall during Rabi Season 2006-07

On 3rd and 4th of December, 13mm rain was reported soon after germination, 3.5mm on 10th of February during shooting and 32.0 mm on 12th March during milk and wax maturity stages.

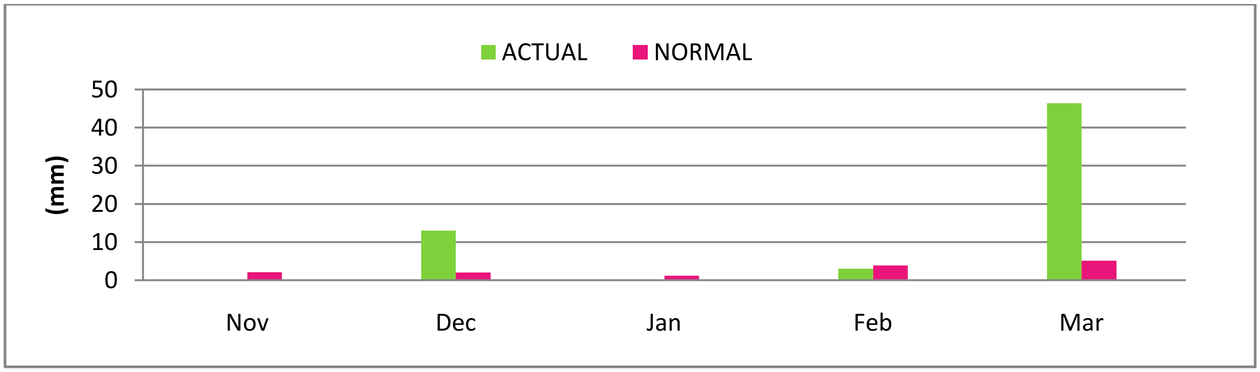


Figure 2.2: Rainfall during 2006-07 in Tandojam

2.2.4 Rainfall during Rabi Season 2007-08

A total of 29 mm rain was reported for 4 days in December, 10mm for two days in January during vegetative growing stages of third leaf, tillering and shooting and 1mm for a single day reported during early maturity stages in March. These rains promoted satisfactory crop growth.

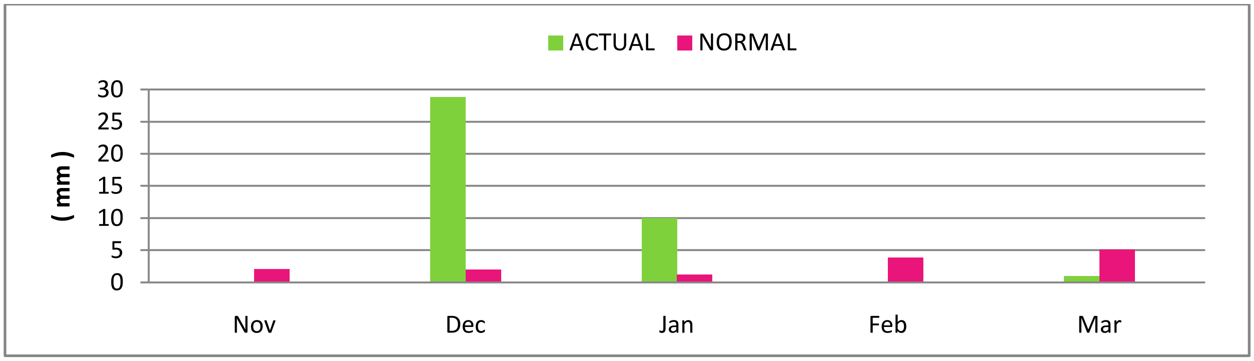


Figure 2.3: Rainfall during 2007-08

2.2.5 Rainfall during the Rabi Season 2008-09

Weather remained dry up to germination. Rain amounted 22 mm recorded in the 2nd decade (16th - 20th) of December during emergence-third leaf stage.

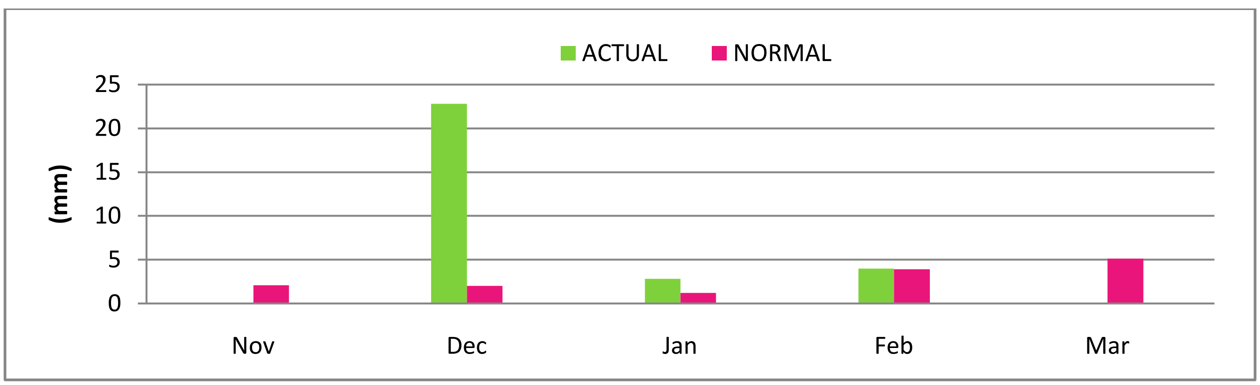


Figure 2.4: Rainfall during 2008-09 in Tandojam

2.2.6Rainfall during the Rabi Season 2009-10

Weather remained almost dry and no significant rain reported during crop life.

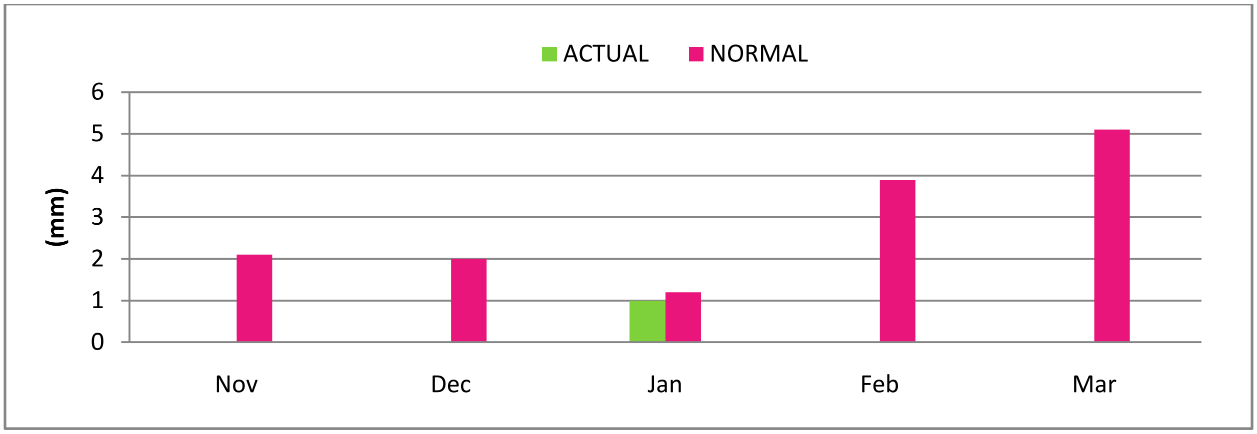


Figure 2.5: Rainfall during 2009-10 in Tandojam

2.2.7 Rainfall during Rabi Season 2010-11

Rainfall amounting 4mm was reported for a single day in November, 23mm for two days in December and 3mm for a single day in January during early to mid growing stages. Trace for a single day was also reported in February and March each.

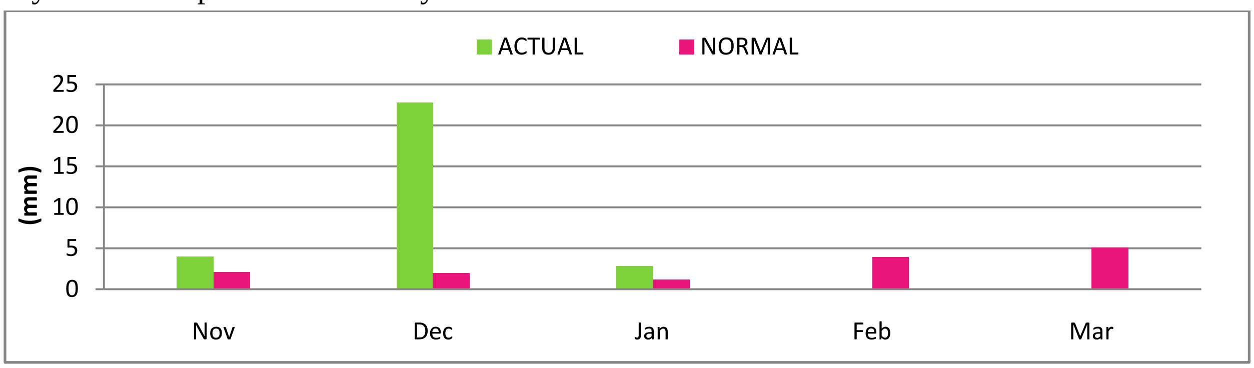


Figure 2.6: Rainfall during 2010-11

2.3 Irrigated Water during Crop Growth

We know that normally, rain occurs during Rabi crops are insufficient to grow wheat crop in agricultural plains of lower Sindh. Therefore variation in the supply of irrigation water on yearly basis is due to several factors affecting directly the growth and yield of wheat crop in the irrigated plains of Sindh.

For satisfactory wheat crop growth, 4-6 times irrigated water is sufficient. First irrigation should be given about 20-25 days after sowing then at the time of need to the crop generally at later stage of tillering, shooting, flowering, late milk and wax maturity stages (Khoso, 1977).

2.3.1 Irrigation during Rabi Season 2005-06

Irrigation water was added **four times** during the crop growth before full maturity. First irrigation was given to the field 22 days after sowing during early growth of third leaf stage. Remaining three irrigation practices were performed during shooting, flowering and early maturity stages.

2.3.2 Irrigation during Rabi Season 2006-07

Irrigation water was added **five times** during the crop growth before full maturity. First irrigation was given to the field 14 days after sowing during growth of third leaf. Remaining four irrigation practices were performed during shooting, flowering and early maturity stages.

2.3.3 Irr igation during Rabi Season 2007-08,

irrigation water was added five times to the field, first irrigation was given after 26 days of sowing, and the remaining four were given each per month at optimum need to the crop and the last one during wax maturity.

2.3.4 Irrigation during Rabi Season 2008-09

Irrigation water was added **four times** to the field, first irrigation was given after 26 days of sowing, and the remaining three were given each per month at optimum need to the crop and the last one during wax maturity.

2.3.5 Irrigation during Rabi Season 2009-10

Irrigation water was added **six times** during the crop growth before full maturity. First irrigation was given to the field 18 days after sowing during growth of third leaf. Remaining five irrigation practices were performed during shooting, flowering and early maturity stages.

2.3.6 Irrigation during Rabi Season 2010-11

irrigation water was added **six times** during the crop growth before full maturity. First irrigation was given to the field 18 days after sowing during early growth of third leaf. Remaining four irrigation practices were performed during shooting, flowering and early maturity stages.

2.4 Air Temperature and Wheat Crop Growth

Air temperature is also one of the most important climatic variables that affect plant growth and development and consequently final yield. Plants growth is restricted to certain limits of air temperature. The main dry matter process i.e. photosynthesis is also temperature dependant. Hence three temperature values for a plant growth are of particular importance. They are;

Biological Zero: is the minimum temperature below which plant growth stops; for wheat crop it ranges between 0 and 5°C.
Optimum Temperature: at which maximum plant growth occurs. For wheat crop its value is 25°C.
Maximum Temperature: above which the plant growth stops. For wheat crop its value is 30-32 °C (Mavi and Graeme, 2005).
The growth and maturity of wheat crop is disturbed at times by abnormal rise in temperature during grain formation stages, due to which the crop is harvested well before its normal harvesting dates and reduced shriveled grain is obtained. An observed case is the wheat crop grown in Sindh during Rabi season 2005-06. During this crop season an abnormal rise in day time temperature in the month of February negatively affected the crop growth and as a result shriveled grain and reduced yield was obtained.

2.4.1 Temperature Regime during Rabi Season 2005-06

During the Crop Season of 2005-06, temperature regime remained normal to below normal during most of the months except in the month of November and February. During February mean daily and day time mean maximum temperature were observed above normal by 3-4^{0}C during early grain formation stages. Due to which early matured reduced grain obtained and final yield of the crop was considerably less than normal. Number of days with moderate (T ≥ 35^{0}C & R.H ≤ 30%) and severe hygrothermal stress days (T≥ 40^{0}C & R.H ≤ 30%) for each month during the entire crop growth period was reported nil.

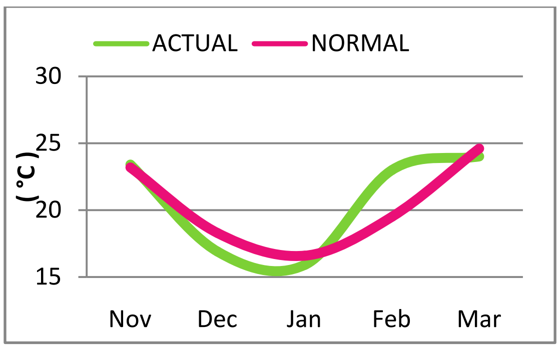


Figure 2.7: Mean Monthly Temperature during 2005-06

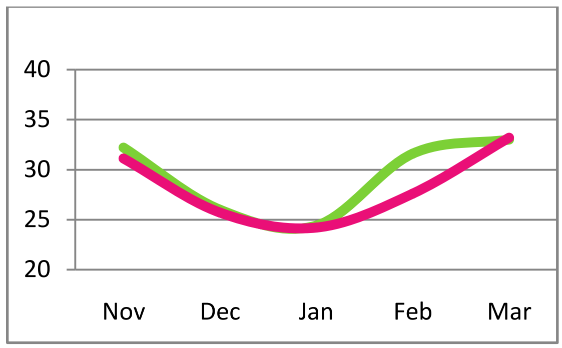


Figure 2.8: Mean Maximum Temperature during 2005-06

Table 2.2: Temperature Regime during Rabi Season 2005-06

Month	Temperature (°C)			Absolute		Mean Temp: ≤ 0	Mean Temp≥35^{0}C R.H≤30%	Max: Temp≥40^{0}C R.H≤30%
	Mean	Mean Max:	Mean Min:	Max:	Min:			
Nov	23.4 (23.2)	32.2 (31.9)	11.0 (17.3)	37.5 (41.0)	7.0 (6.0)	0	0	0
Dec	16.9 (18.3)	26.0 (26.3)	10.0 (12.5)	30.0 (35.6)	4.5 (3.0)	0	0	0
Jan	15.9 (16.6)	24.4 (25.0)	8.5 (11.1)	28.0 (35.0)	5.0 (-1.0)	0	0	0
Feb	23.0 (19.5)	31.6 (28.1)	10.6 (13.6)	35.0 (39.0)	5.5 (2.0)	0	0	0
Mar	24.0 (24.6)	33.0 (33.9)	15.0 (18.5)	38.0 (47.0)	10.5 (5.0)	0	0	0

Note: Normal values are enclosed in brackets.

2.4.2 Temperature Regime during Rabi Season 2006-07

During the Crop Season of 2006-07, temperature regime mostly remained normal to below normal during crop's life except in the month of February (flowering and early maturity stages) during which daily mean and day time maximum temperature remained slightly above normal. Number of moderate ($T \geq 35^0C$ & $R.H \leq 30\%$) and severe ($T \geq 40^0C$ & $R.H \leq 30\%$) hygrothermal stress days for each month during the entire crop growth period was reported nil, which is a good indicator for better growth at all stages. Hence it is concluded that temperature regime throughout the crop life was almost favorable for the crop.

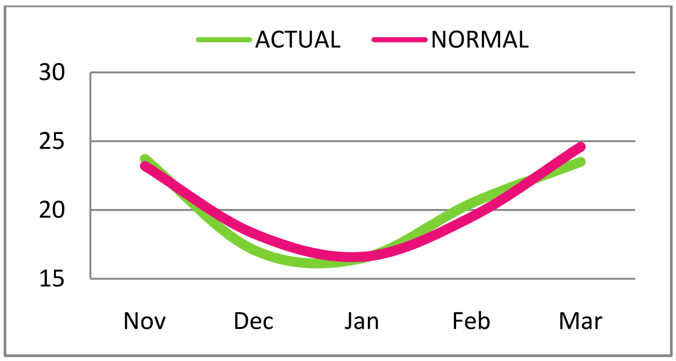


Figure 2.9: Mean Monthly Temperature during 2006-07

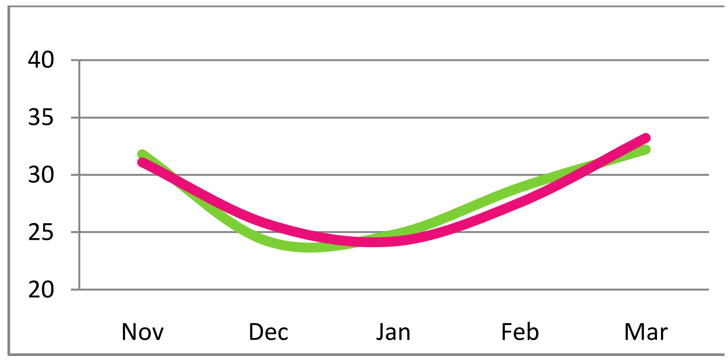


Figure 2.10: Mean Maximum Temperature during 2006-07

Table 2.3: Temperature Regime during Rabi Season 2006-07

Month	Temperature (^{0}c)			Absolute		Mean Temp: ≤ 0	Mean Temp≥35^{0}C R.H≤30%	Max: Temp≥40^{0}C R.H≤30%
	Mean	Mean Max:	Mean Min:	Max:	Min:			
Nov	23.7 (23.2)	31.8 (31.3)	15.5 (15.0)	37.5 (41.0)	7.0 (6.0)	0	0	0
Dec	17.1 (18.3)	24.2 (25.7)	9.9 (10.8)	30.0 (35.6)	4.5 (3.0)	0	0	0
Jan	16.5 (16.6)	24.8 (24.2)	8.2 (9.0)	28.0 (35.0)	5.0 (-1.0)	0	0	0
Feb	20.5 (19.5)	28.9 (27.6)	12.2 (11.4)	35.0 (39.0)	5.5 (2.0)	0	0	0
Mar	23.5 (24.6)	32.2 (33.2)	15.1 (16.0)	38.0 (47.0)	10.5 (5.0)	0	0	0

2.4.3 Temperature Regime during Rabi Season 2007-08

Mean daily and day time maximum temperature remained normal to above normal during most of the crop's life, particularly during early growing stages and during grain formation stages.

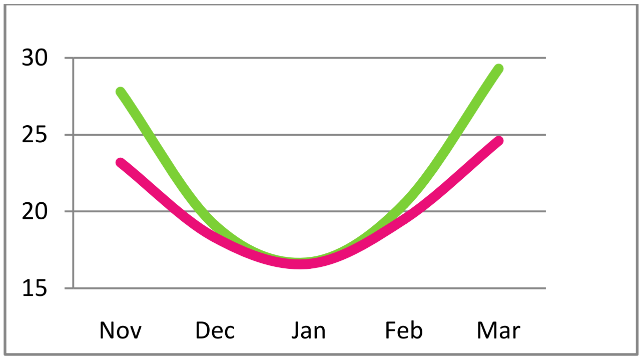


Figure 2.11: Mean Monthly Temperature during 2007-08

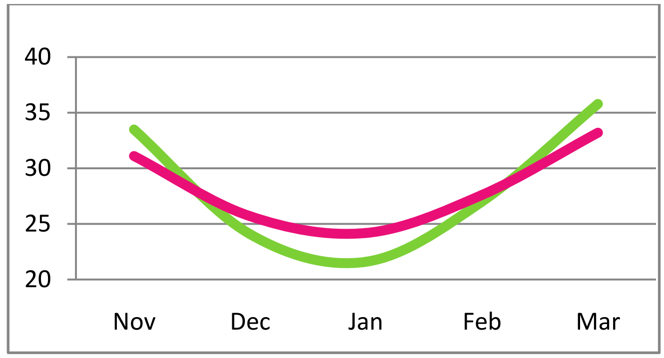


Figure 2.12: Mean Maximum Temperature during 2007-08

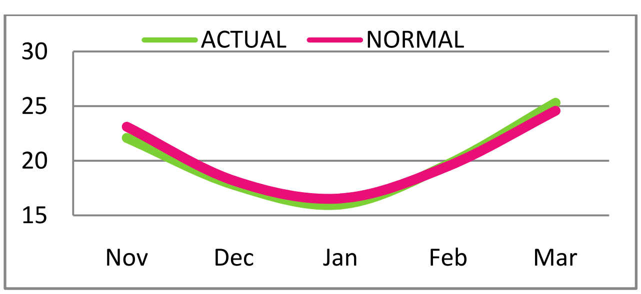
Table 2.4:- Temperature Regime during Rabi Season 2007-08

Month	Mean Monthly (°C)	Monthly Mean Max. (°C)	Mean monthly Min (°C)	Absolute Max. (°C)	Absolute Min. (°C)
Nov	27.8 (23.1)	33.5 (31.1)	14.2	38.5	11.5
Dec	19.1 (18.2)	24.1 (25.7)	8.4	29.5	3.5
Jan	16.7 (16.6)	21.6 (24.2)	6.2	27	1.5
Feb	20.5 (19.5)	27 (27.6)	6.1	35.3	-0.4
Mar	29.3 (24.6)	35.8 (33.2)	14.7	40.5	11

2.4.4 Temperature Regime during Rabi Season 2008-09

During Crop Season of 2008-09, temperature regime remained normal to below normal throughout the crop period except in the months of February and March during shooting and maturity stages when mean daily temperature remained slightly above normal.

Number of moderate ($T \geq 35^0C$ & R.H $\leq 30\%$) and severe ($T \geq 40^0C$ & R.H $\leq 30\%$) hygrothermal stress days for each month during the entire crop growth period was reported nil. Hence it is concluded that temperature regime throughout the crop life was almost favorable for the crop at all stages.



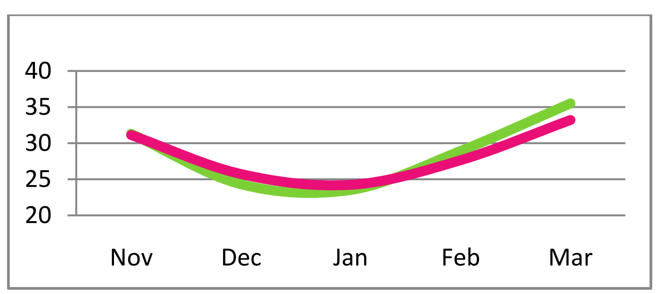


Figure 14: Mean Maximum Temperature during 2008-09

Figure 3. 13:Mean Monthly Temperature during 20008-09

Table2.5: Temperature Regime during Rabi Season 2008-09

Month	Temperature (^{0}C)			Absolute		Mean temp $\geq 35^0$C	Maximum temp $\geq 40^0$C
	Mean	Mean Max:	Mean Min:	Max:	Min:	R.H≤30%	R.H≤30%
Nov	22.1 (23.2)	31.3 (31.3)	12.8 (15.0)	37.5 (41.0)	7.0 (6.0)	0	0
Dec	17.8 (18.3)	24.3 (25.8)	11.4 (10.8)	30.0 (35.6)	4.5 (3.0)	0	0
Jan	16.0 (16.6)	23.5 (24.6)	8.5 (9.0)	28.0 (35.0)	5.0 (-1.0)	0	0
Feb	19.7 (19.5)	28.9 (27.6)	10.6 (11.4)	35.0 (39.0)	5.5 (2.0)	0	0
Mar	25.3 (24.6)	35.5 (33.2)	15.0 (16.0)	38.0 (47.0)	10.5 (5.0)	0	0

2.4.5 Temperature Regime during Rabi Season 2009-10

During Crop Season of 2009-10, temperature regime remained normal to below normal throughout the crop period except in the months of February and March during shooting and maturity stages when mean daily and day time maximum temperature remained slightly above normal. Number of moderate (T≥35^{0}C & R.H ≤30%) and severe (T≥ 40^{0}C & R.H ≤ 30%) hygrothermal stress days for each month during the entire crop growth period was reported nil.

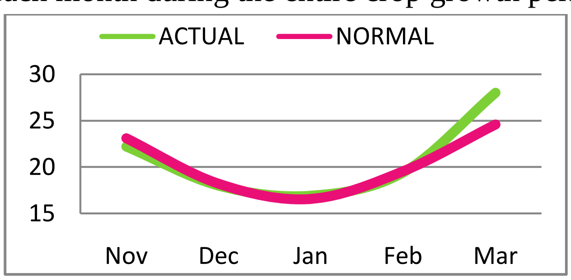


Figure 3. 15:Mean Monthly Temperature during 2009-10

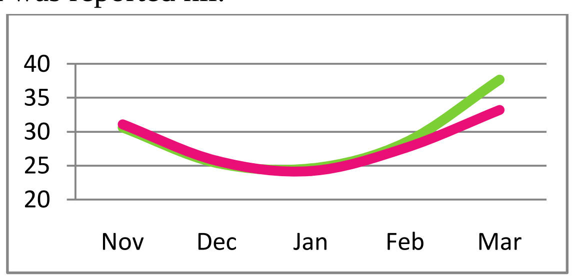


Figure 3. 16: Mean Maximum Temperature during 2009-10

Table 2.2:Temperature Regime during Rabi Season 2009-10

Month	Temperature (^{0}C)			Absolute		Mean Temp ≤ 0	Mean Temp≥35^{0}C R.H≤30%	Max: Temp≥40 ^{0}C R.H≤30%
	Mean	Mean Max:	Mean Min:	Max:	Min:			
Nov	22.2 (23.2)	30.6 (31.3)	13.8 (15.0)	38.5 (41.0)	10.4 (6.0)	0	0	0
Dec	18.0 (18.3)	25.4 (25.8)	10.5 (10.8)	29.0 (35.6)	6.0 (3.0)	0	0	0
Jan	16.9 (16.6)	24.6 (24.2)	9.1 (9.0)	29.0 (35.0)	6.0 (-1.0)	0	0	0
Feb	19.4 (19.5)	28.4 (27.6)	10.3 (11.4)	37.0 (39.0)	4.5 (2.0)	0	0	0
Mar	28.0 (24.6)	37.7 (33.2)	18.3 (16.0)	41.0 (47.0)	13.3 (5.0)	0	0	0

2.4.6 Temperature Regime during Rabi Season 2010-11

Mean daily and day time maximum temperature remained normal to below normal during early growing stages and remained normal during grain formation stages, which favored satisfactory crop growth.

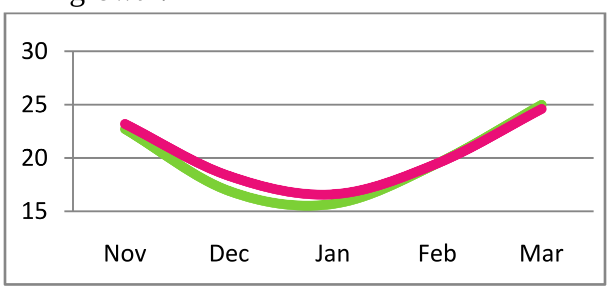


Figure 2. 17: Mean Monthly Temperature during 2010-11

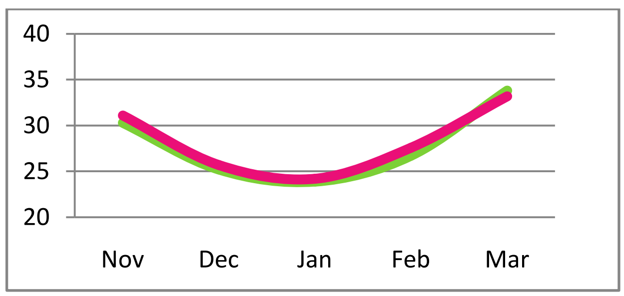


Figure 2. 18: Mean Maximum Temperature during 2010-11

Table 2.7:- Temperature Regime during Rabi Season 2010-11

Month	Mean Monthly (°C)	Monthly Mean Max. (°C)	Mean monthly Min (°C)	Absolute Max. (°C)	Absolute Min. (°C)
Nov	22.7 (23.1)	30.3 (31.1)	15.3	35.0	10.0
Dec	16.9 (18.2)	25.2 (25.7)	8.6	29.0	3.5
Jan	15.7 (16.6)	23.9 (24.2)	7.9	28.5	5.0
Feb	19.5 (19.5)	26.7 (27.6)	12.2	31.5	9.0
Mar	25.0 (24.6)	33.8 (33.2)	16.1	40.0	10.8

2.5 Soil Moisture Observation during Crop Growth

Soil moisture plays a vital role during crop's life. Soil moisture content is proportional to rainfall and intake of irrigated water and is inversely proportional to evapotranspiration from the plant and its surroundings. Variation in soil moisture during crop's life play important role in plant growth and development. Water or soil moisture requirement of wheat crop varies during different growth or Phenological stages. Highest amount is needed during flowering stage followed by grain formation stages and then vegetative stages (FAO Technical paper No.33).

In order to measure the soil moisture at different phenological stages, the most common and widely used, Gravimetric method was applied.

To calculate soil moisture, soil samples are taken on 7th, 17th and 27th of each month from the four replications at 5, 10, 20, 30, 40, 50, 70, 90 and 110 cm depths with the help of auger. However in case of any anomalous event on the specific date, the sample can also be taken on the next day. Soil sample is then weighed and dried in the oven for about 8 hours. The dried sample is weighed again and moisture present in the soil is then calculated by the difference of weight between wet and dry samples as illustrated below;

$$\text{Moisture (in \%)} = \frac{(\text{weight of the cane containing soil before drying} - \text{weight of the cane containing dry soil})}{\text{Weight of cane containing dry soil} - \text{weight of cane}} \times 100$$

Moisture contents of the soil varied due to dry and wet spells throughout the season. These fluctuations were more prominent in the shallow layers of the soil. After each effective irrigation or rain the moisture level increased more in the shallow layers as compared to deep layers of the soil. Followed by some dry spells, the soil moisture decreased more sharply in shallow layers than deep soils.

2.5.1 Soil Moisture during Rabi Season 2005-06

From the Figures (2.19 to 2.21), it is evident that soil moisture content was more satisfactory at deep layers than at shallow layers. Moisture deficiency to some extent is noted in February and March during Maturity stages due to normal/above normal air and soil temperature in these months. Deficiency in the soil moisture was partially compensated through canal irrigation.

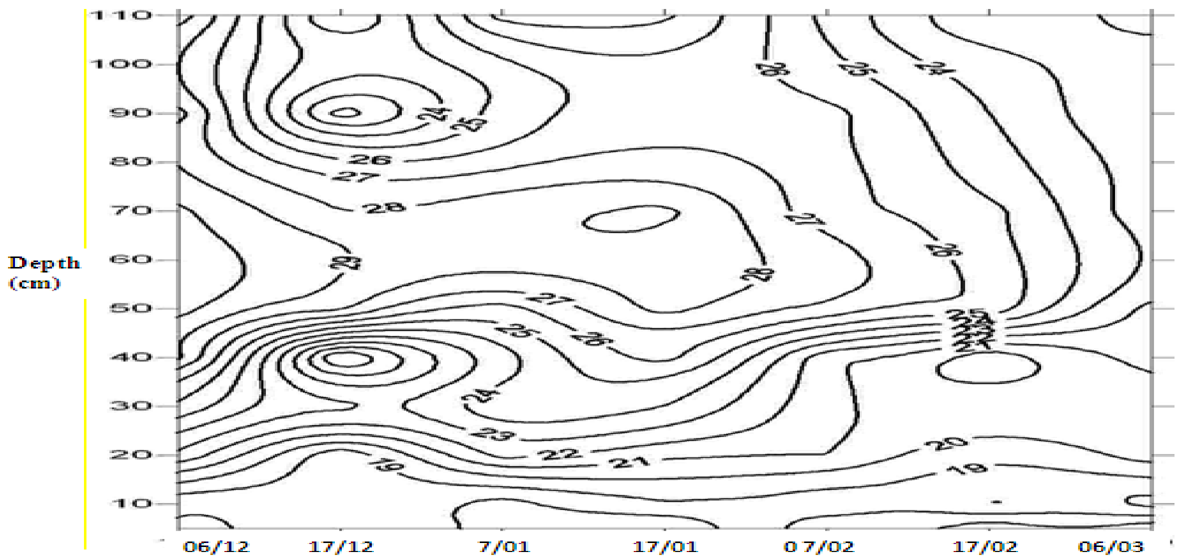


Figure 2.19: Soil moisture chrono Iso-Plantss for Rabi Crop at Tandojam for the year 2005-06

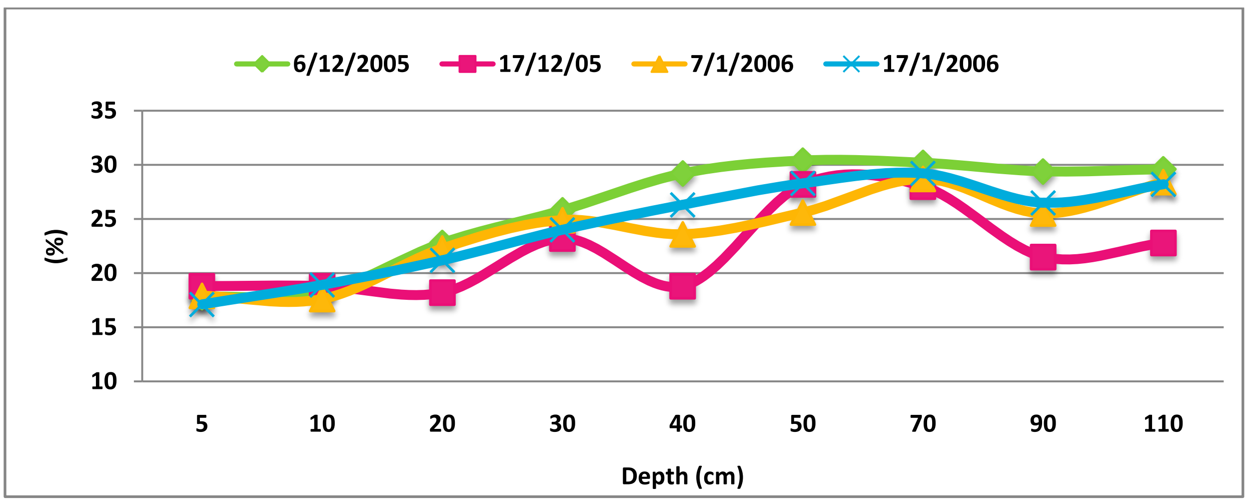


Figure 2. 20: Soil Moisture at different depths during Dec-2005 to Jan-2006

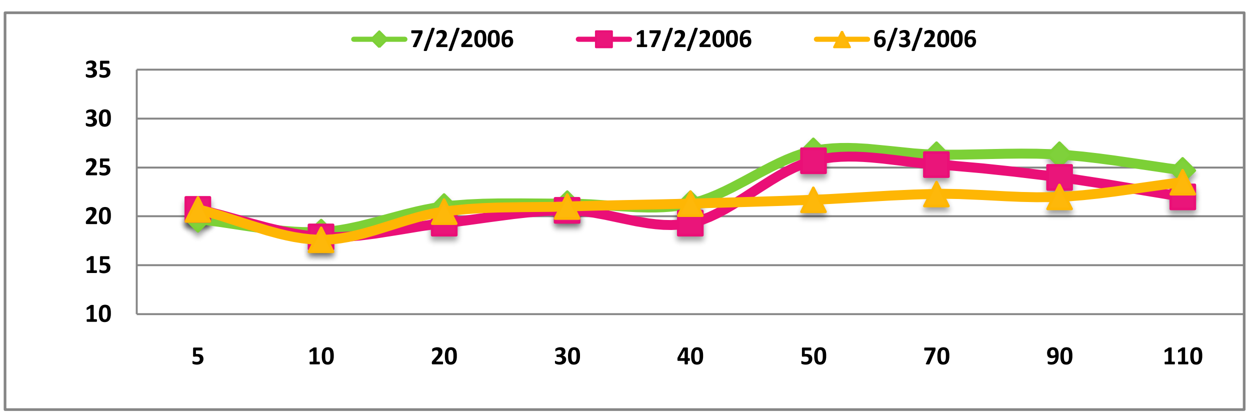


Figure 2.21: Soil Moisture at different depths during Feb to Mar-2006

2.5.2 Soil Moisture during Rabi Season 2006-07

Soil moisture data of the crop is not available. However due to above normal soil and air temperature data in the months of November and February, soil moisture content might have reduced in these months. However moisture content was maintained at satisfactory level partially by irrigation.

2.5.3 Soil Moisture during Rabi Season 2008-09

From the observed soil moisture data, Figure 2.22, it is evident that soil moisture decreased at the completion of third leaf and beginning of tillering stage in the end of December particularly at shallow layers. Moisture content also decreased to some extent in March. However the soil moisture deficiency for the crop was compensated through canal irrigation and satisfactory rainfall during the season.

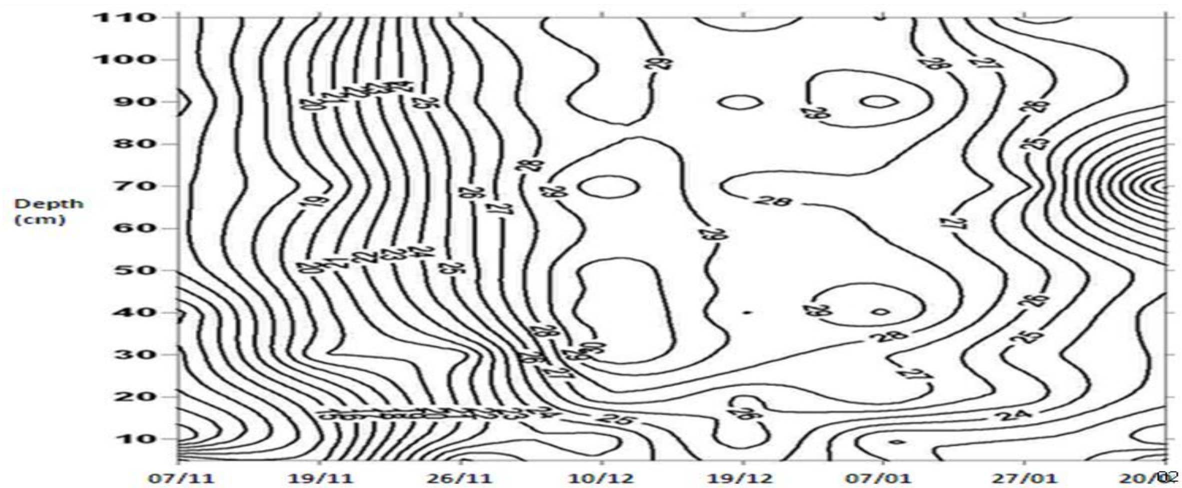


Figure 2.22: Soil Moisture Chrono Iso-Planths during the crop year 2008-09

2.5.4 Soil Moisture during Rabi Season 2009-10

Due to in time irrigation, the soil moisture content was observed satisfactory during crop's life. Figures 2.22 to 2.25 also indicate that moisture content was more satisfactory below 10cm depths at root zone and deep layers. Overall

Condition of soil moisture was observed satisfactory for the crop growth during the crop season 2009-10. Below normal soil temperature data of 2009-10 during most of the crop's period also verifies satisfactory moisture condition during the crop's growth.

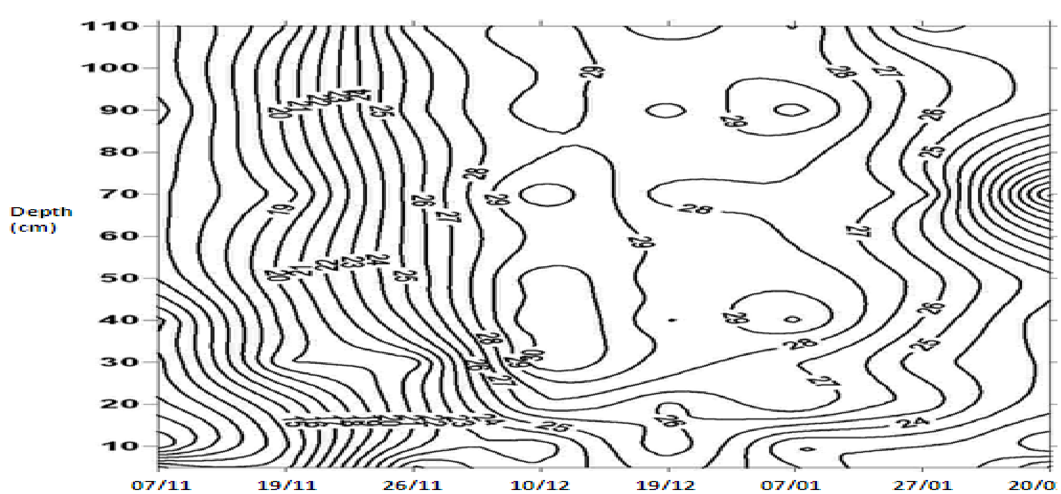


Figure 2. 4: Soil moisture chrono Isopleths for Rabi Crop at Tandojam for the year 2009-10

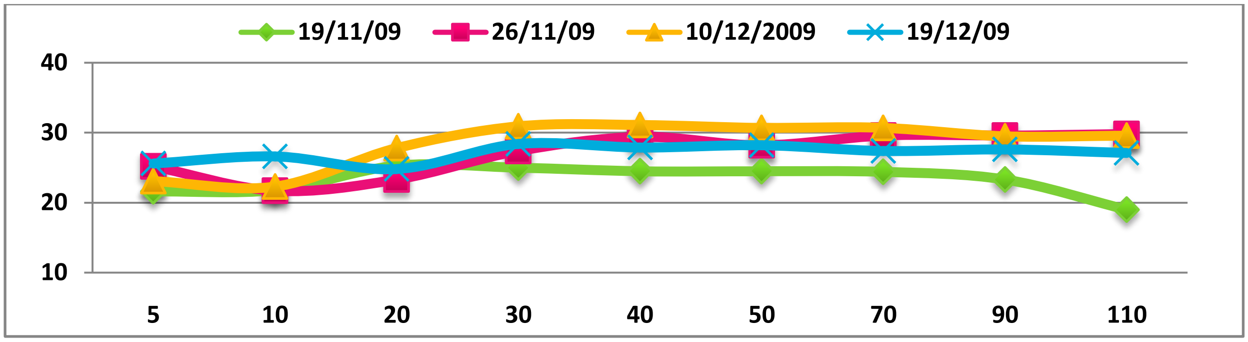


Figure 2.5: Soil moisture during Nov-Dec 2009

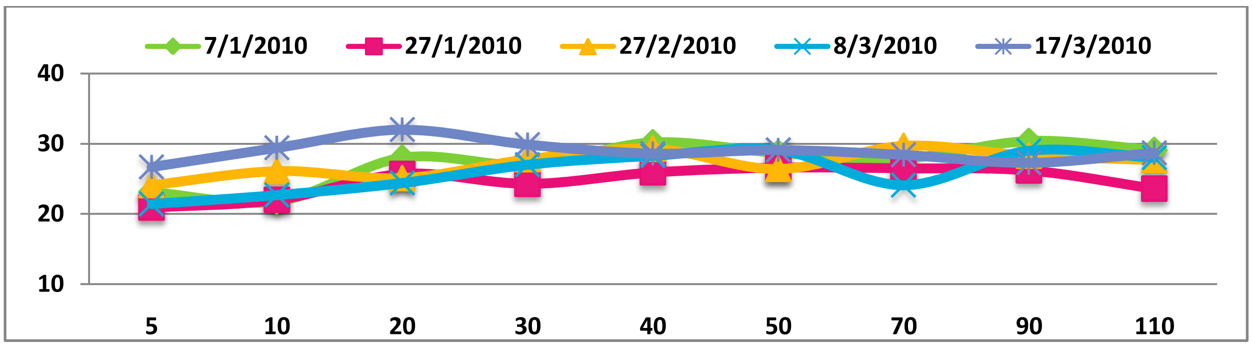


Figure 2.25: Soil moisture during Jan-Mar 2010

2.5.6 Soil Moisture Observations during Crop Season 2010-11

During the crop season of 2010-11, from the observed soil moisture data (Figures 2.26 to 2.29), it is evident that soil moisture mostly satisfactory due to in time irrigation and satisfactory rains during the crop life.

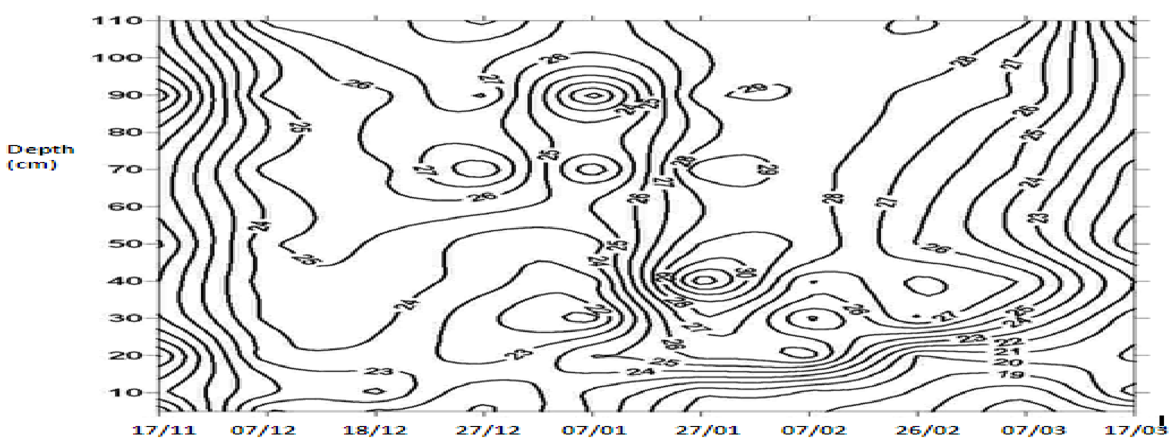


Figure 2.26: Soil Moisture Chrono Iso-Planths for Rabi Crop for the year 2010-11

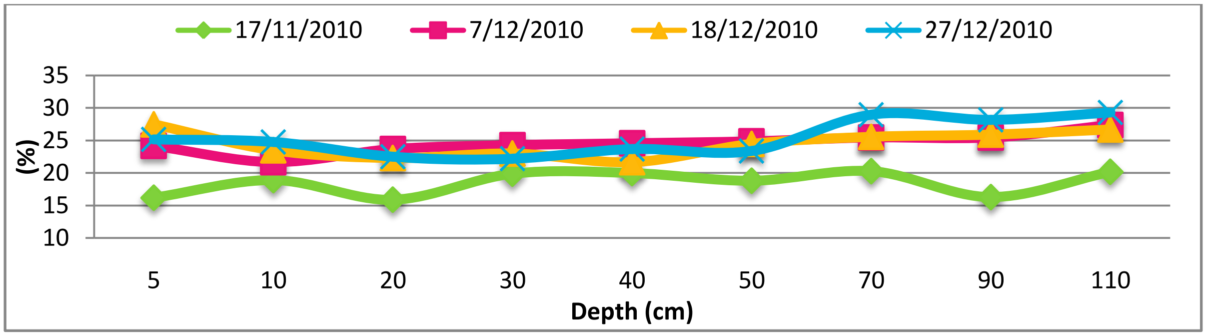


Figure 2. 27: Soil moisture during Nov to Dec-2010

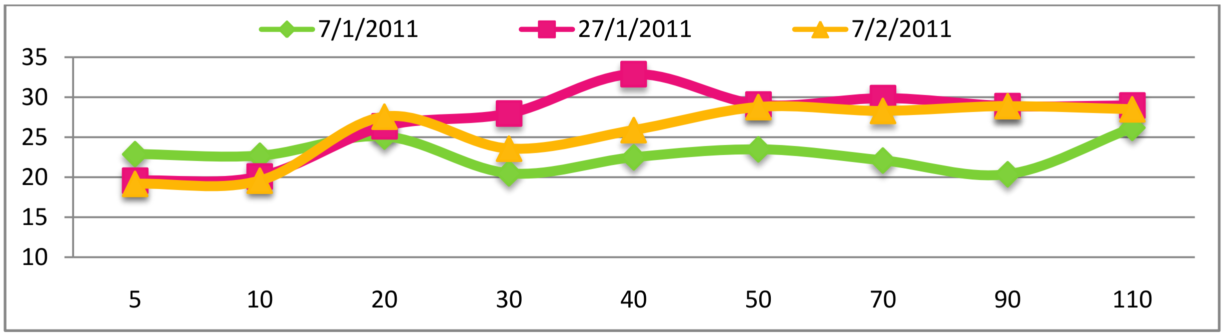


Figure 2.28: Soil moisture during Jan-Feb 2011

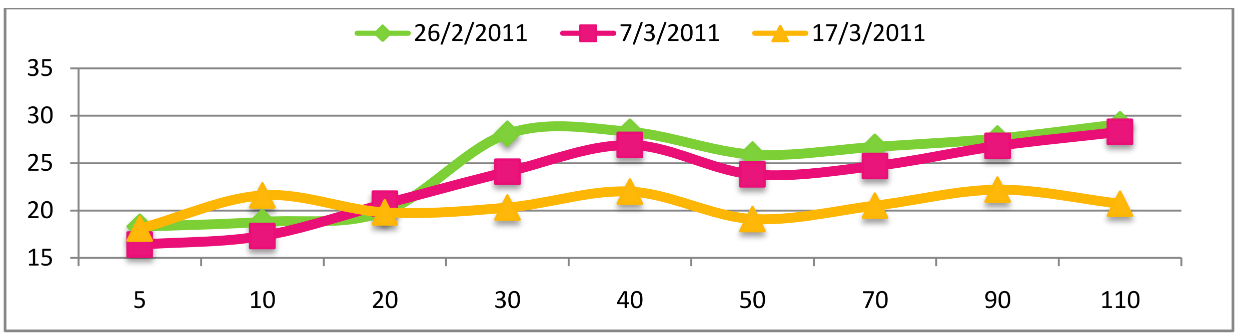


Figure 2.29: Soil moisture during Feb-Mar 2011

2.6 Soil Temperature and Crop Growth

Soil temperature also plays an important role in crop life. Soil temperature affects germination and the rate of plant growth and development. Soil temperature more than 35^0C has shown negative effect on terminal root growth (Mavi and Graeme, 2005).

These upper limits of soil temperature were crossed significantly by soil during later grain formation stages when crops were cultivated late (e.g., 2001-02 2002-03 and 2003-04 crop years). This sharp rise in soil temperature also played significant role in reduction of final yield during these years.

Soil temperature is also an easy tool to predict the status of soil moisture content during varying conditions of air and soil throughout crop's life. Generally above normal condition of soil temperature at a particular depth indicates deficiency of soil moisture content and below normal soil temperature indicates satisfactory condition of soil moisture content.

From the observed data, it is evident that generally, soil temperature increases gradually with increasing depths. Diurnal variations in soil temperature are more significant at shallow layers than deep soils. Soil temperature varies as soil moisture varies from depth to depth and time to time. Soil thermometers in ^{0}C were installed at depths of 5 cm, 10 cm, 20 cm, 30 cm, 50 cm and 100 cm to monitor thermal regime of the soil. The soil temperature was observed and then recorded three times a day i.e. 0300, 0900 and 1200 UTC.

Note: This soil temperature data is collected from the soil observations taken at Agromet observatory of R.A.M.C Tandojam situated near the experimental field of wheat crop. Therefore this data tells us a general status of soil moisture of the soils of the area (which is not irrigated) and not of the crop's field particularly, which is irrigated as per requirement. It is thus important to note that any deficiency in soil moisture indicated by soil temperature data may or may not be actually experienced by the crop's soil, which was irrigated in accordance with water requirement of the crop several times during its life time.

2.6.1 Soil Temperature (°C) during Rabi Season 2005-06

During crop season 2005-06, soil temperature was observed above normal at shallow root zone as well as in deep layers during early growing stages in November and during shooting and grain formation stages in February and March. Whereas it was observed normal to below normal during intermediate growing stages of third leaf and shooting stages in the months of December and January. This above normal rise in soil temperature also negatively affected crop growth during early and later grain formation stages.

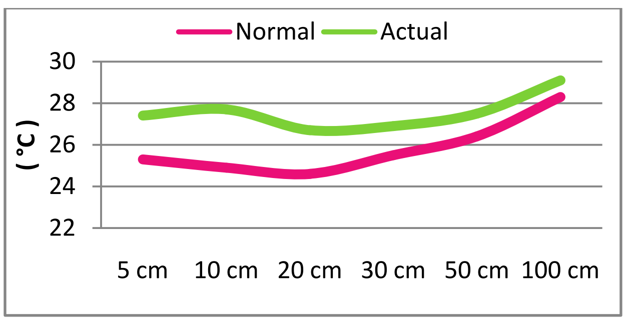


Figure 2.30: Soil temperature during Nov-2005

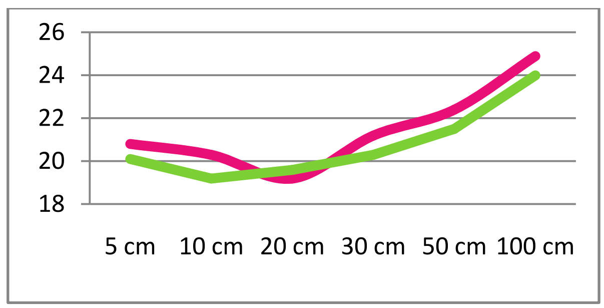


Figure 2.31: Soil temperature during Dec-2005

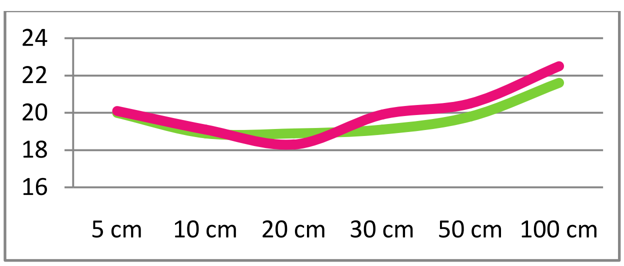


Figure 2.32: Soil temperature during Jan-2006

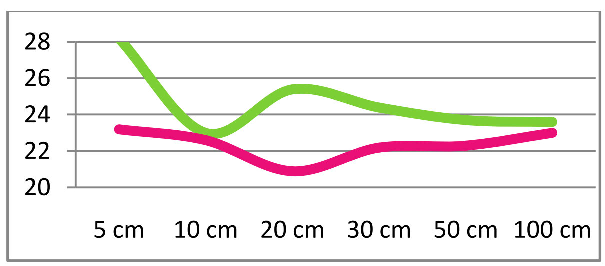


Figure 2.33: Soil temperature during Feb-2006

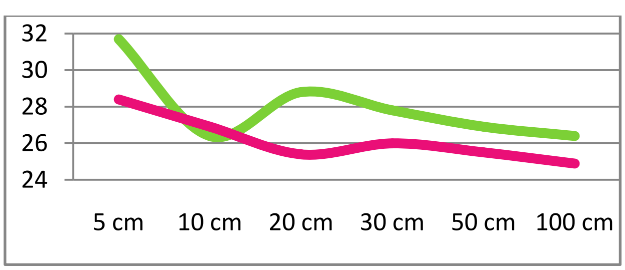


Figure 2.34: Soil temperature during Mar-2006

2.6.2 Soil Temperature during 2006-07

During crop season 2006-07, soil temperature remained above normal at early germination stage in November and during shooting/flowering stage in February due to above normal rise in air temperature in this month. Whereas soil temperature remained normal to below normal during early growing vegetative stages in December and January and during maturity stages in March. These above normal temperatures in mentioned months may produce moisture stress; however, due to unavailability of moisture data of the crop season, it could not be verified. This above normal rise also played negative role in crop growth to some extent during the mentioned period.

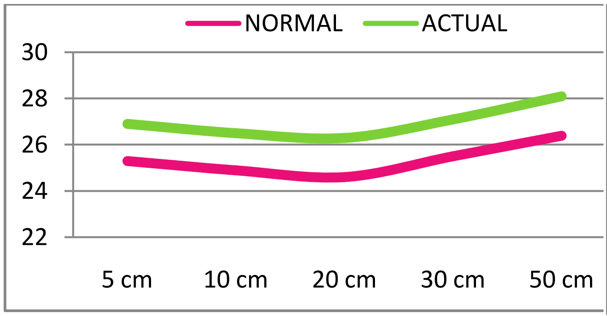


Figure 2.35: Soil temperature during Nov-2006

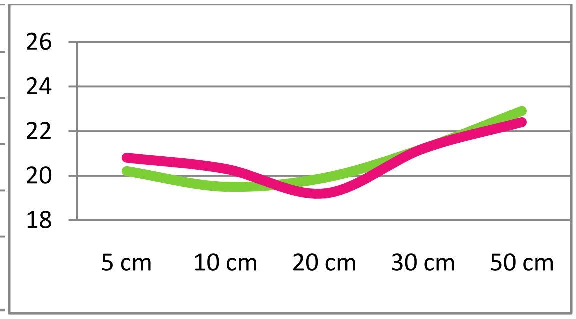


Figure2.36: Soil temperature during Dec-2006

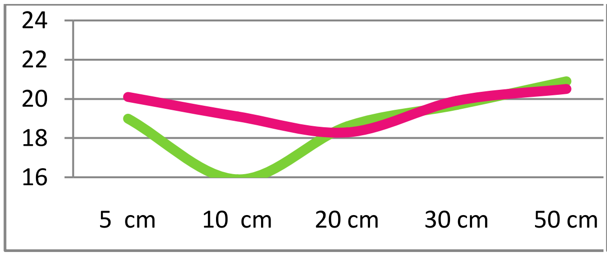


Figure2. 67: Soil temperature during Jan-2007

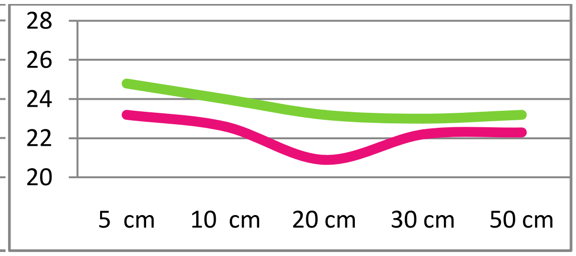


Figure 2. 78: Soil temperature during Feb-2007

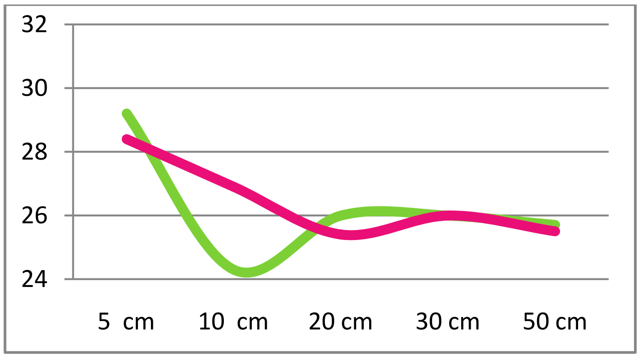


Figure2. 89: Soil temperature during Mar-2007

2.6.3 Soil Temperature during Rabi Season 2007-08

During crop season of 2007-08, Soil temperature mostly remained normal to below normal during most of the vegetaive and grain formation stages except during early growth in November and during maturity in March it remained above normal, which affected crop growth to some extent.

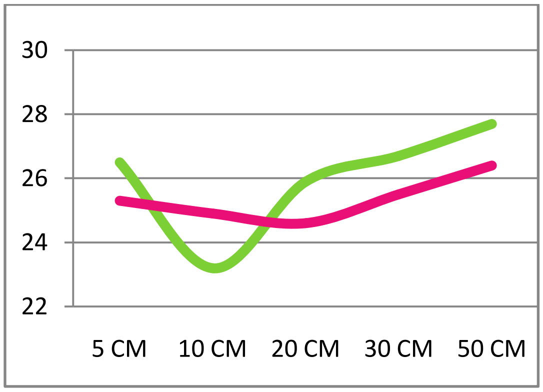


Figure 2.40: Soil temperature during Nov-2007

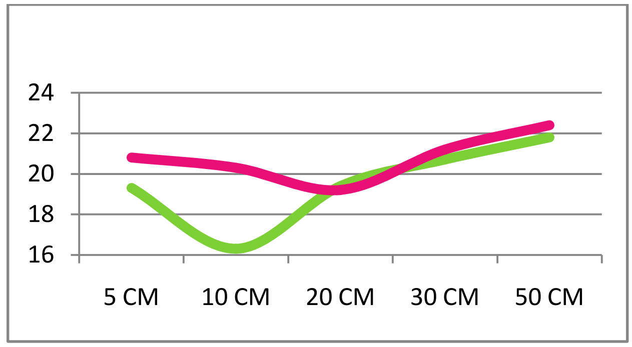


Figure 2.41: Soil temperature during December -2007

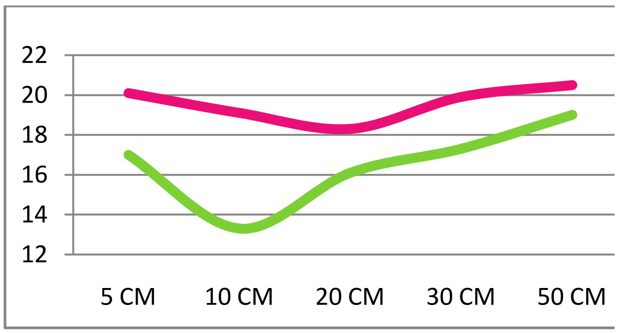


Figure 2.42: Soil temperature during Jan-008

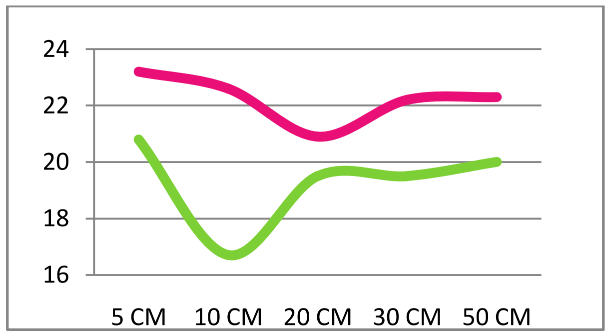


Figure 2.43: Soil temperature during Feb-2008

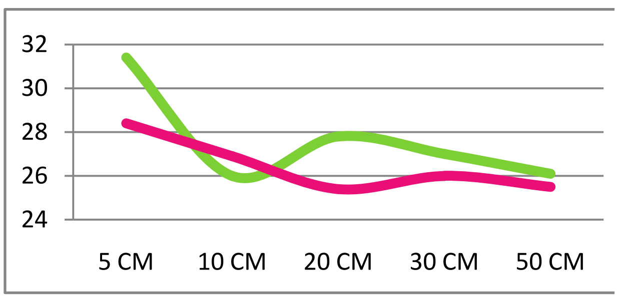


Figure 2.44: Soil temperature during Mar-2008

2.6.4 Soil Temperature during Rabi Season 2008-09

During crop season 2008-09, soil temperature remained above normal during later grain formation stages (Feb & Mar) in both shallow as well as deep layers. But due to in time rainfall and irrigation water during the crop season resulted normal crop growth.

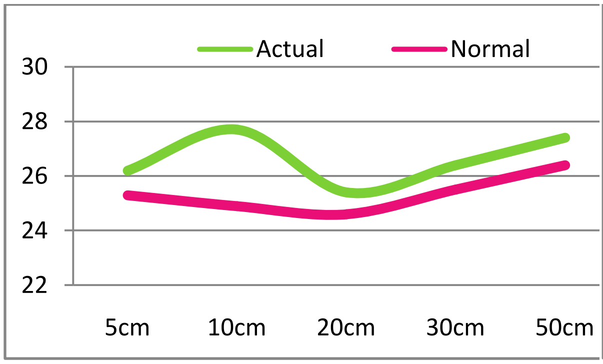


Figure 2. 45: Soil temperature during Nov-2008

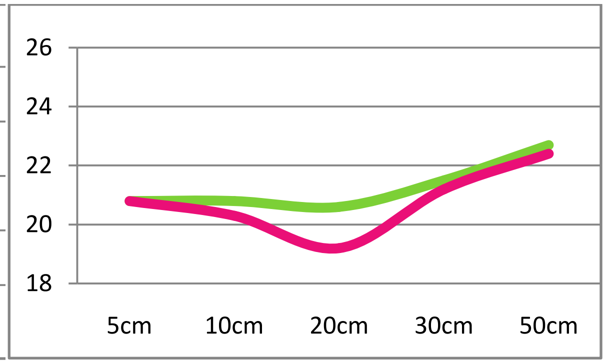


Figure 2. 46: Soil temperature during Dec-2008

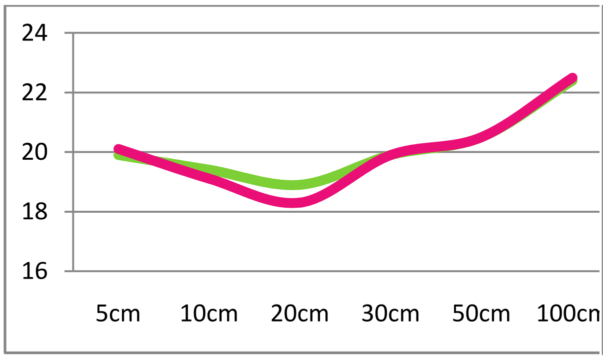


Figure 2. 47: Soil temperature during Jan-2009

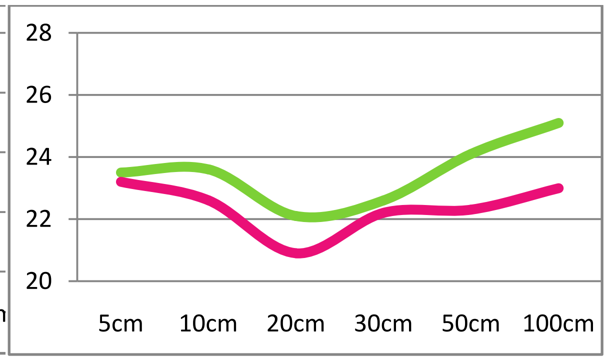


Figure 2. 48: Soil temperature during Feb-2009

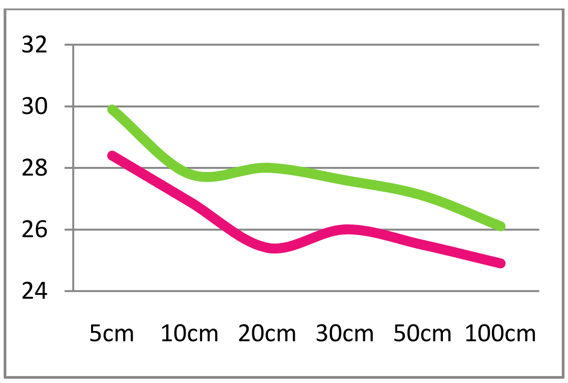


Figure2. 49: Soil temperature during Mar-2009

2.6.5Soil Temperature during Rabi Season 2009-10

During crop season 2009-10, soil temperature remained mostly normal to below normal at shallow as well as deep layers except during maturity stages in March. The rise in soil temperature in March is more significant at shallow layers than deep soils. Overall status of soil temperature observed satisfactory for crop growth.

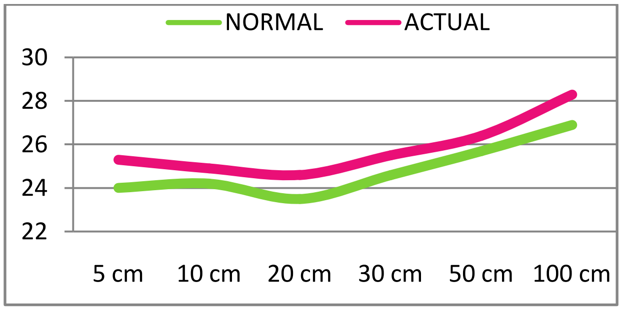


Figure 2. 50: Soil temperature during Nov-2009

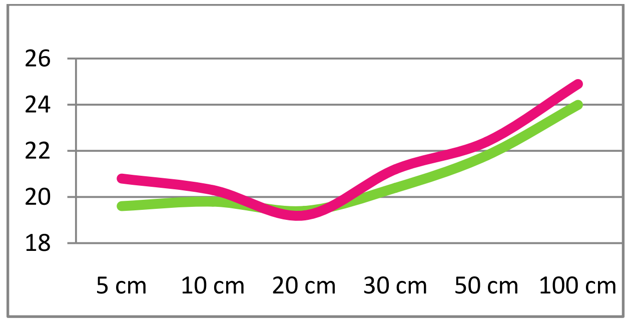


Figure 2. 51: Soil temperature during Dec-2009

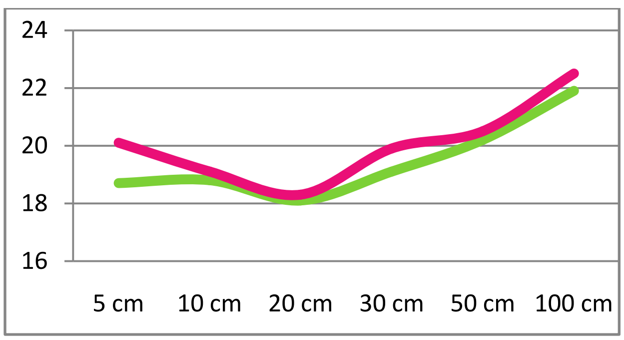


Figure 2. 52: Soil temperature during Jan-2010

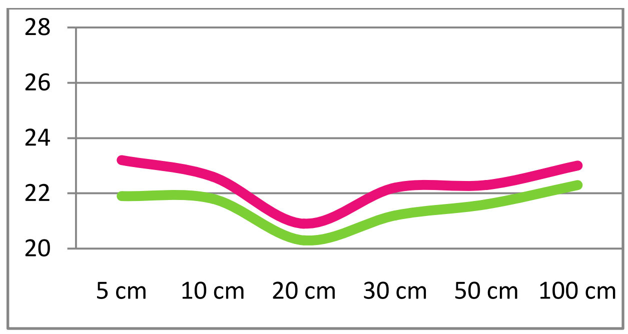


Figure 2. 53: Soil temperature during Feb-2010

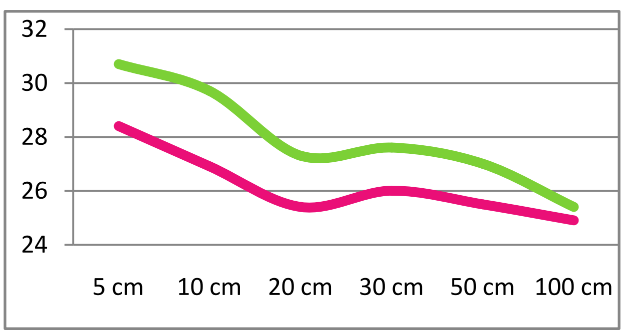


Figure 2. 54: Soil temperature during Mar-2010

2.6.6 Soil Temperature during Rabi Season 2010-11

During the crop season 2010-11, soil temperature remained normal to below normal throughout crop life, which indicates satisfactory moisture condition of soil at shallow as well as deep layers.

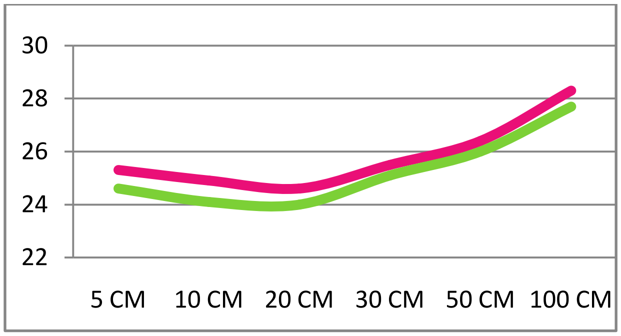


Figure 2. 55: Soil temperature during Nov-2010

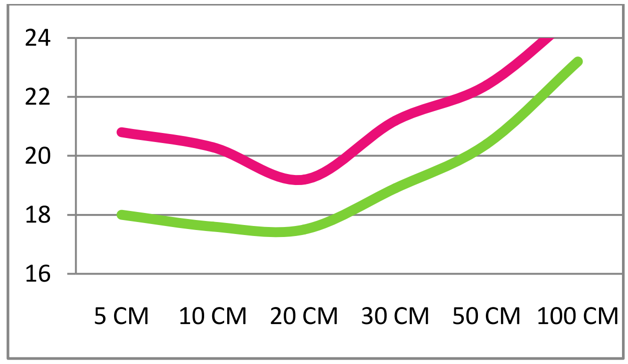


Figure 2. 56: Soil temperature during Dec-2010

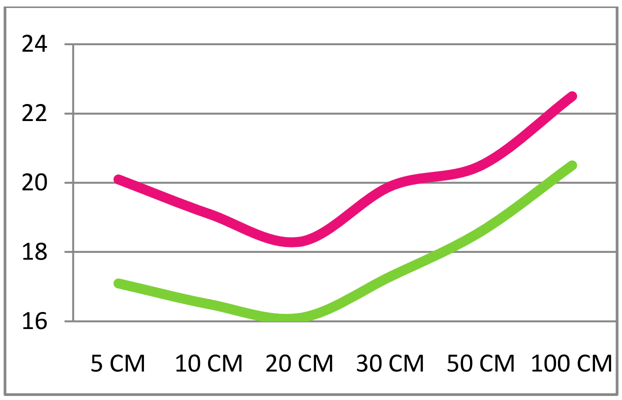


Figure 2. 57: Soil temperature during Jan-2011

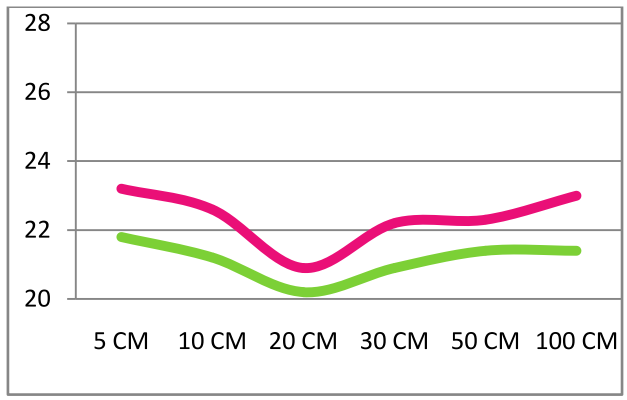


Figure 2. 58: Soil temperature during Feb-2011

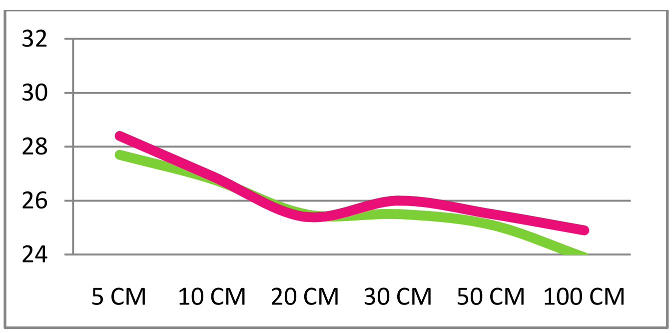


Figure 3. 59: Soil temperature during Mar-2011

2.7 Heat Units Consumption during Crop Growth (Crop Variety TD-1)

2.7.1 Heat Units Consumption and Crop Growth

Heat units or Growing Degree Days very easily relates plant growth, development, and maturity to air temperature. It can be used to predict the completion of a particular phenological stage or complete maturity of the crop (Mavi and Graeme, 2005).

Therefore heat units consumption decides full maturity/ harvesting or completion of a particular phase of the crop. Heat units thus provides an authentic guess to predict the Phenological phase appearance and hence the maturity of the crop. As we all know, there are large variations in temperature from day to day and season to season. The use of thermal time or heat units rather than calendar time takes this variability into consideration and provides an explanation for differences in crop maturity when observations from different years are compared (Hashmi, 1989).

For instance during crop season 2005-06, abnormal rise in daily temperature during early maturity stages in February, the crop matured or developed earlier but its dry matter formation or crop growth remained incomplete, resulting low yield and reduced size grain. Same case repeated during Rabi season in 2001-02 and 2002-03 wheat crops matured earlier due to rising day time temperatures in the month of March and April as a result of late sowing.

But sometimes drought, pest and disease, and variation of nitrogen and phosphorous in the soil may vary heat units requirement of the same variety year to year.

2.7.2 Methods of Calculations of Heat Units

There are two major methods of calculation of the degree days and they are known as active and effective methods. Calculation procedure is mentioned below.

(a) Effective Method: This is simply the temperature sum during the period under consideration e.g. emergence to flowering etc.

$H.U = \sum T$; T is mean daily temperature.

$= 0$: if $T \leq Tb$; where Tb is biological zero, which is the temperature below which growth stops. For wheat crop its value is 5°C. Crops go in dormancy when temperature drops below the biological zero.

(b) Active Method: This method incorporates the biological zero or base temperature of the crop, Heat units with effective method are calculated as under:

$H.U = \sum (T - T_b)$ if $T > T_b$; $H.U = 0$ if $T < T_b$

In the present case, heat units were calculated by effective method as mean daily temperature never drops below biological zero in lower Sindh.

2.7.3 Heat Units consumed by the crop during the period 2005-06 to 2010-11

Interphase period for wheat crop during the crop seasons observed at different Phenological stages varies from phase to phase and crop to crop. Average heat unit requirement of different phases and cumulative heat units for the crop have been worked out and are shown in Table 3.7. Average values of heat units consumed by the crop during the period 2005-06 to 2010-11 were 2349 accumulated from sowing to full maturity in 122 days.

Table 2. 3: Average Heat Units Accumulation for Wheat Crop during 2005-06 to 2010-11

Inter phase	**Inter-Phase duration (days)**	**Heat units**
Sowing – Emergence	14	298
Emergence–Third leaf	24	430
Third leaf–Tillering	25	401
Tillering–Shooting	11	175
Shooting–Heading	7	114
Heading–Flowering	13	277
Flowering–Milk maturity	9	185
Milk maturity–Wax maturity	10	226
Wax maturity –Full maturity	10	244
Sowing – Full maturity	122	2349

Table 2. 9: Heat Units Accumulation for Wheat Crop during 2005-06

Inter phase	Period	Inter-Phase duration (days)	Heat units
Sowing – Emergence	17-11-05 to 30-11-05	13	289
Emergence–Third leaf	1-12-05 to 25-12-05	25	435
Third leaf–Tillering	26-12-05 to 20-1-06	26	414
Tillering–Shooting	21-1-06 to 31-1-06	11	185
Shooting–Heading	1-2-06 to 5-02-06	5	102
Heading–Flowering	6-2-06 to 17-2-06	10	280
Flowering–Milk maturity	18-2-06 to 24-02-06	7	172
Milk maturity–Wax maturity	25-02-06 to 6-3-06	10	227
Wax maturity –Full maturity	7-3-06 to 16-3-06	10	230
Sowing – Full maturity	17-11-05 to 16-03-2006	117	2334

Table 2. 10: Heat Units Accumulation for Wheat Crop during 2006-07

Inter phase	Period	Inter-Phase duration(days)	Heat units
Sowing – Emergence	28-11-06 to 14-12-06	17	286
Emergence–Third leaf	15-12-06 to 9-1-07	26	430
Third leaf–Tillering	10-1-07 to 1-02-07	23	404
Tillering–Shooting	2-01-07 to 10-02-07	9	186
Shooting–Heading	11-2-07 to 17-2-07	7	136
Heading–Flowering	18-02-07 to 2-3-07	13	274
Flowering–Milk maturity	3-3-09 to 10-03-07	8	180
Milk maturity–Wax Maturity	11-03-09 to 20-03-07	10	223
Wax maturity –Full maturity	21-03-09 to 30-03-07	10	258
Sowing – full maturity	28-11-06 to 26-3-07	123	2377

Table 2. 4:- Heat Units Accumulation for the Crop during 2007-08

Inter -phase observed	Period	Inter- Phase Duration	Heat units
Sowing – Emergence	9-11-07 to 20-11-07	12	286
Emergence–Third leaf	21-11-07 to 10-12-07	20	426
Third leaf–Tillering	11-12-07 to 7-01-08	28	413
Tillering–Shooting	8-01-08 to 19-01-08	12	180
Shooting–Heading	20-01-08 to 28-01-08	9	115
Heading–Flowering	29-01-08 to 10-02-08	13	287
Flowering–Milk maturity	11-02-08 to 19-02-08	9	179
Milk maturity–Wax maturity	20-02-08 to 28-02-08	9	238
full maturity	1-03-08 to 8-03-08	9	232
Sowing to Full Maturity	9-11-2007 to 9-03-2008	121	2356

Table 2. 12 : Heat Units Accumulation for Wheat Crop during 2008-09

Inter phase	Period	Inter-Phase duration(days)	Heat units
Sowing – Emergence	28-11-08 to 12-12-08	15	301
Emergence–Third leaf	13-12-08 to 7-1-09	26	437
Third leaf–Tillering	8-1-09 to 2-01-09	26	411
Tillering–Shooting	3-01-09 to 12-02-09	10	176
Shooting–Heading	13-2-09 to 18-2-09	6	113
Heading–Flowering	19-02-09 to 2-3-09	12	278
Flowering–Milk maturity	3-3-09 to 10-03-09	8	183
Milk maturity–Wax Maturity	11-03-09 to 19-03-09	9	220
Wax maturity –Full maturity	20-03-09 to 29-03-09	10	263
Sowing – full maturity	28-11-08 to 29-3-09	122	2382

Table 2. 53: Heat Units Accumulation for Wheat Crop during 2009-10

Inter phase	Period	Inter-Phase duration(days)	Heat units
Sowing – Emergence	10-11-09 to 23-11-09	14	289
Emergence-Third leaf	24-11-09 to 16-12-09	23	437
Third leaf- Tillering	17-12-09to 08-01-10	23	400
Tillering- Shooting	09-01-10 to 19-01-10	11	171
Shooting-Heading	20-01-10 to 25-01-10	06	102
Heading- Flowering	26-01-10 to 08-02-10	14	274
Flowering-Milk maturity	09-02-10 to 19-02-10	11	181
Milk maturity-Wax maturity	20-02-10 to 01-03-10	10	229
Wax maturity – Full maturity	02-03-10 to 11-03-10	10	250
Sowing – Full maturity	10-11-09 to 11-03-10	122	2333

Table 2.14 Heat Units Accumulation for the Crop during 2010-11

Inter-phase	Period	Inter-phase duration	Heat units
Sowing – Emergence	06-11-10 to 19-11-10	14	334
Emergence-Third leaf	20-11-10 to 11-12-10	22	416
Third leaf- Tillering	12-12-10 to 02-01-11	22	363
Tillering- Shooting	03-01-11 to 13-01-11	11	150
Shooting-Heading	14-01-11 to 20-01-11	07	117
Heading- Flowering	21-01-11 to 04-02-11	15	269
Flowering-Milk maturity	05-02-11 to 15-02-11	11	213
Milk maturity-Wax maturity	16-02-11 to 26-02-11	11	216
Wax maturity – Full maturity	27-02-11 to 08-03-11	11	230
Sowing to Full maturity	06-11-10 to 08-03-11	124	2309

2.8 Other Meteorological Parameters during Crop Growth

Other important meteorological parameters relating to crop's growth and development include Relative Humidity represented by R.H, Reference crop evapotranspiration represented by Eto and Wind speed .Relative humidity or *R.H is simply defined as the ratio of the actual amount of water vapor (grams) in the unit mass of air at a given temperature to the mass of water vapour in the same sample of air when it is saturated at the same temperature. R.H tells us about how much a sample of air around the observing station is saturated. It is expressed in percentage. For example if relative humidity of the atmosphere is 60%.It means that 60% of the atmosphere is saturated with water vapor or moisture and 40% of the present moisture may be added more to saturate(100% R.H) the atmosphere. R.H is temperature and moisture dependent and may vary if moisture content or temperature of the atmosphere is changed. It is always inversely proportional to temperature and Eto. R.H is calculated with the help of dry bulb and wet bulb temperatures fitted in the Stevenson screen.*

***Reference Crop Evapotranspiration** or Eto (According to FAO technical paper on water management for crops) is defined as the rate of Evapotranspiration from an extended surface of 8 – 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground, free from disease and not short of water. The standard method of calculating Eto is revised Penman-Monteith equation. By this method, Eto is calculated using data of temperature (maximum and minimum), wind speed, solar radiation and relative humidity. Whereas solar radiation is calculated with the help of total bright sunshine hours data and bright sunshine hours data of a particular station is recorded using sunshine recorder with sunshine card.*

Wind also play significant role in plant growth besides its role in variation of Eto.

Normal/ gentle wind is necessary for the movement of carbon dioxide, CO_2 to plant canopy so that normal rate of photosynthesis continue in day time. Strong cyclonic or stormy wind accompanied by any severe weather event like hail storm, heavy shower may badly affect/damage the crop. During the Rabi crop period 2000-2011, no such bad weather event was observed. Wind speed was observed mostly normal and any significant wind speed accompanied by any severe weather event was not observed throughout this period.

2.8.1 Relative Humidity and ETo during Rabi Season 2005-06

During the crop season of 2005-06, Relative humidity was observed above normal and ETo remained below normal except in the month of February (flowering and early maturity stages), during which ETo remained above normal.

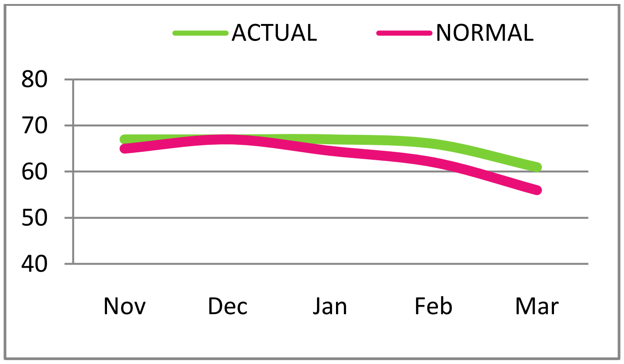


Figure 3. 60: Mean Relative Humidity(%) during 2005-06

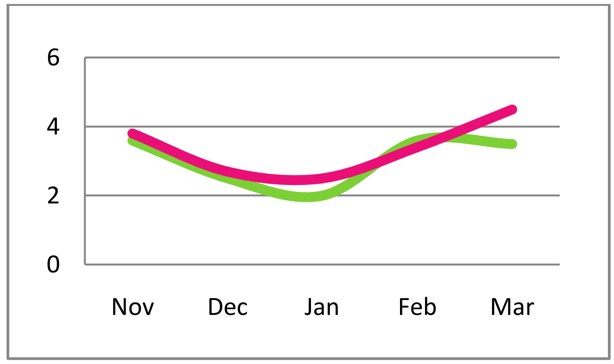


Figure 2.61: ETo (mm/day)during 2005-06

Table 2. 6: Summary of some Meteorological Parameters during Rabi Season 2005-06

Month	Wind Speed (Km/Hr)	R.H (%)	No. of days with R.H≥ 70-80%	ETo (mm/day)
Nov	2.3 (5.1)	67 (65)	01	3.6 (3.8)
Dec	2.5 (4.9)	67 (67)	01	2.5 (2.7)
Jan	3.5 (5.2)	67 (64.5)	01	2.0 (2.5)
Feb	3.5 (5.7)	66 (62)	01	3.6 (3.4)
Mar	4.3 (5.7)	61 (56)	01	3.5 (4.5)

2.8.2 Relative Humidity and ETo during Rabi Season 2006-07

During the crop season of 2006-07, Relative humidity was observed above normal and reference crop evapotranspiration represented by ETo remained below normal during crop's life. Both were favorable for satisfactory crop growth.

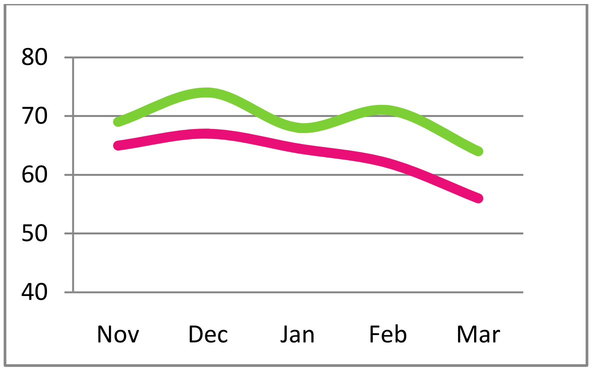


Figure 2.62: Mean Relative Humidity(%) during 2006-07

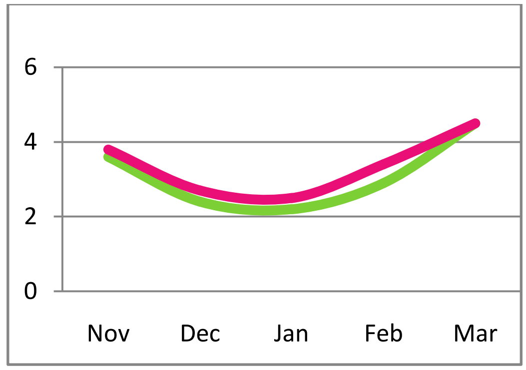


Figure 2.63: ETo (mm/day)during 2006-07

Table 2 76: Summary of some Meteorological Parameters during Rabi Season 2006-07

Month	SPEED (km/Hr)	R.H (%)	No. of days with R.H≥ 70-80%	Eto (mm/day)
Nov	2.1 (5.1)	69 (65)	01	3.6 (3.8)
Dec	2.2 (4.9)	74 (67)	03	2.4 (2.7)
Jan	2.4 (5.2)	68 (64.5)	01	2.2 (2.5)
Feb	2.6 (5.7)	71 (62)	02	2.9 (3.4)
Mar	3.7 (5.7)	64 (56)	02	4.5 (4.5)

2.8.3 Relative Humidity and ETo during Crop Season 2007-08

During the crop season 2007-08, relative humidity remained normal to below normal during most of the crop growing period. However during full maturity in March it was observed above normal. ETo remained above normal during most of the growing period. However it remained below normal in December and January during tillering and shooting stages.

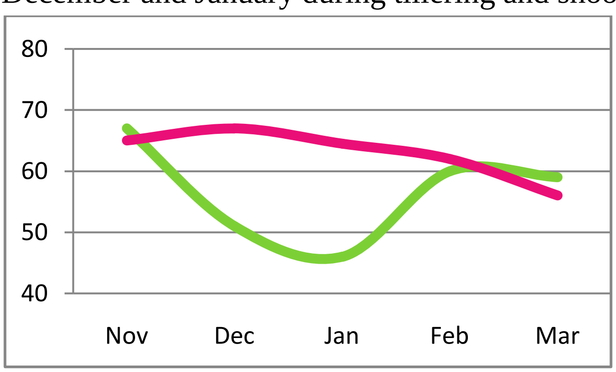


Figure 2. 64: Mean Relative Humidity(%) during 2007-08

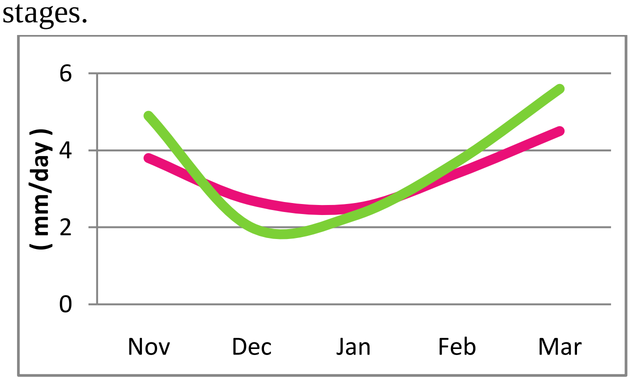


Figure 2. 65: ETo (mm/day)during 2007-08

Table 2.8: Summary of some Meteorological Parameters during Rabi Season 2007-08

Month	Wind speed (km/hr)	R.H (%)	Days with mean RH ≥80%	ET0 Mm/day
Nov	2.3 (5.1)	67 (47)	00	4.9 (4.8)
Dec	2.7 (4.9)	51 (49)	02	2.0 (3.9)
Jan	3.4 (5.2)	46 (48)	02	2.3 (3.7)
Feb	2.8 (5.7)	60 (45)	00	3.7 (3.9)
Mar	3.7 (5.7)	59 (43)	00	5.6 (5.1)

2.8.4 Relative Humidity and ETo during Rabi Season 2008-09

Relative humidity was observed normal to below normal during most of the crop period whereas it remained above normal during December. ETo remained below normal during crop's life.

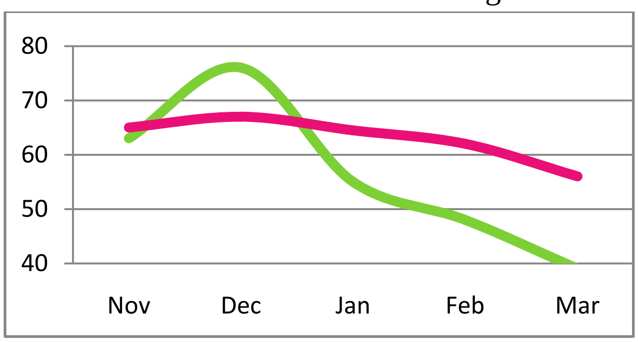


Figure 2. 66: Mean Relative Humidity(%) during 2008-09

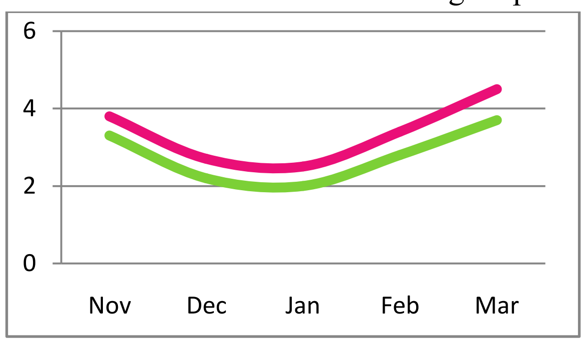


Figure 2. 67 : ETo (mm/day)during 2008-09

Table 2.18 : Summary of some Meteorological Parameters during Rabi Season 2008-09

Month	Wind Speed (km/Hr)	R.H (%)	No. of days with R.H ≥ 70-80%	Eto (mm/day)
Nov	3.4 (5.1)	63 (65)	00	3.3 (3.8)
Dec	2.1 (4.9)	76 (67)	11	2.2 (2.7)
Jan	2.9 (5.2)	55 (64.5)	02	2.0 (2.5)
Feb	2.6 (5.7)	48 (62)	02	2.8 (3.4)
Mar	3.0 (5.7)	39 (56)	00	3.7 (4.5)

2.8.5 Relative Humidity and ETo during Crop Season 2009-10

Relative humidity was observed normal to above normal during crop's life except during the months of November and December during early growing stages it remained below normal and ETo remained normal to above normal during crop's life except in the month of January, during which ETo values remained slightly below normal.

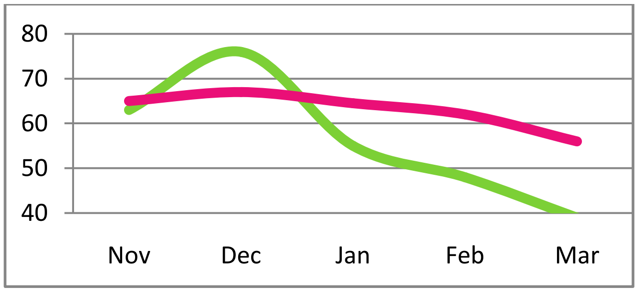


Figure 2. 68: Mean Relative Humidity(%) during 2009-10

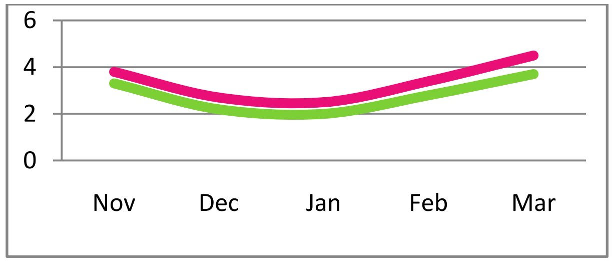


Figure 2. 69 : ETo (mm/day)during 2009-10

Table 2. 9: Summary of some Meteorological Parameters during Rabi Season 2009-10

Month	Wind Speed (km/Hr)	R.H (%)	No. of days with R.H≥ 70-80%	Eto (mm/day)
Nov-09	2.0 (5.1)	61 (65)	00	3.9 (3.8)
Dec-09	2.2 (4.9)	65 (67)	01	3.0 (2.7)
Jan-10	2.2 (5.2)	71 (64.5)	03	2.1 (2.5)
Feb-10	1.9 (5.7)	64 (62)	01	3.6 (3.4)
Mar-10	4.1 (5.7)	59 (56)	00	6.2 (4.5)

2.8.6 Relative Humidity and ETo during Crop Season 2010-11

During the crop season 2010-11, relative humidity remained normal to below normal during most of the crop growing period and ETo remained normal during most of the growing period. Overall soil and air moisture content was very favorable for crop growth due to in time irrigation and rainfall during crop life.

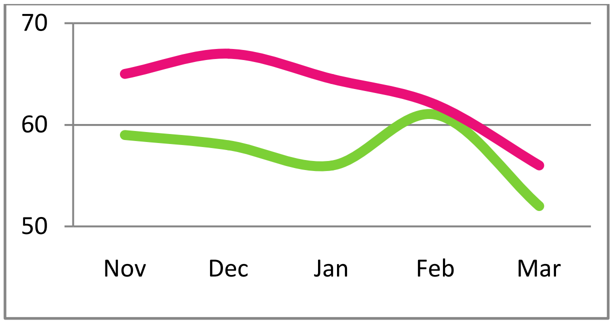


Figure 3. 70: Mean R.H during 2010-11

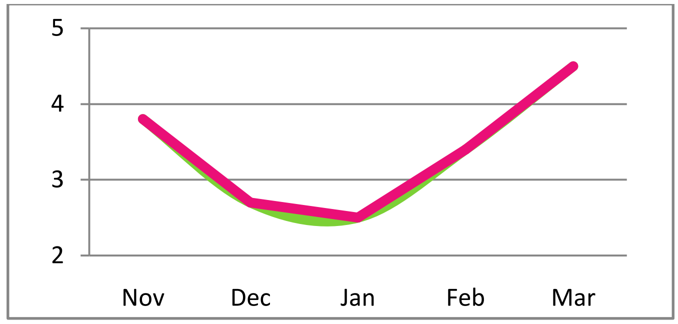


Figure 3. 71: Mean ETo during 2010-11

Table 2.20: Summary of some Meteorological Parameters during Rabi Season 2010-11

Month	Wind speed (km/hr)	R.H (%)	Days with mean RH ≥80%	ET0 Mm/day
Nov	1.6 (5.1)	59 (65)	01	2.5 (3.8)
Dec	1.7 (4.9)	58 (67)	00	1.9 (2.7)
Jan	2.3 (5.2)	56 (64.5)	00	2.1 (2.5)
Feb	2.4 (5.7)	61 (62)	01	2.7 (3.4)
Mar	3.1 (5.7)	52 (56)	00	4.2 (4.5)

2.9 Crop Water Requirement (CWR) during the Rabi Season in Tandojam

The crop water requirement (CWR) is defined as the amount of water needed to the crop, to balance the loss through evapotranspiration.
The crop water need mainly depends upon the climate of crop area, crop type and phenological stage of the crop.

2.9.1 Calculation of Crop Water Requirement (CWR)

After determining ETo, crop water requirement (CWR) can be calculated by the following equation using crop-coefficient (Kc)

$$CWR = Kc.\ ETo$$

Variation of the crop coefficient during different crop stages under normal conditions is given in Figure 3.51(Naheed, 2009).

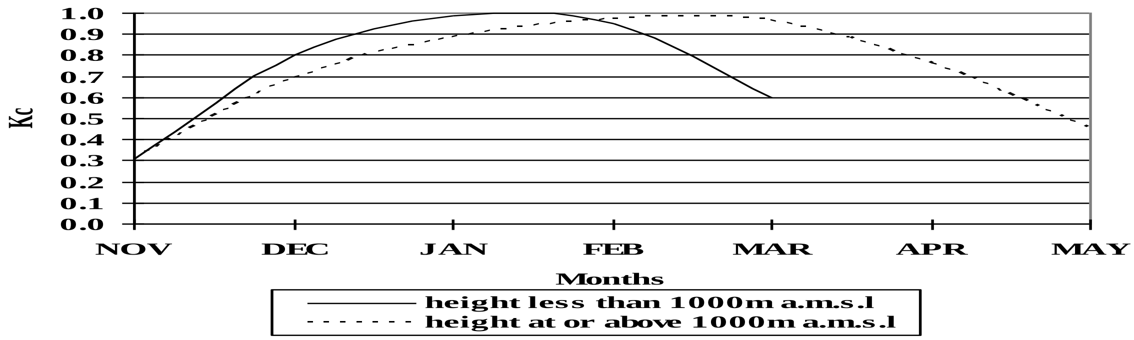


Figure 2. 9: March of Crop Coefficient (Kc) for normal duration of Wheat growing season

2.9.2 Crop Water Requirement during the Rabi Season 2005-06 in Tandojam

Crop water requirement of wheat crop was observed mostly normal to below normal during most of the crop growth (Fig 2.72 & Table 2.21). However it remained slightly above normal during some intermediate stages (shooting to flowering) due to above normal temperature observed in February.

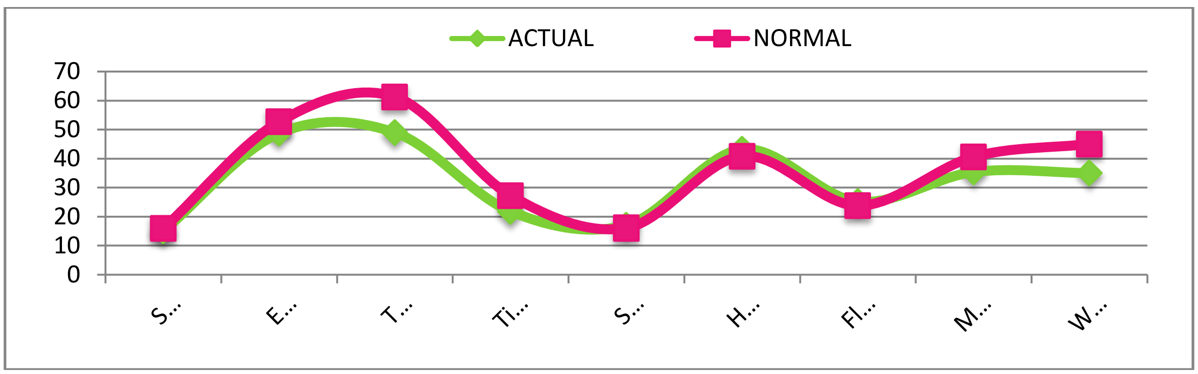


Figure 2.72: comparison of CWR with Normal values during the crop life.

Table 2.21: Crop Water Requirement during 2005-06

Inter-phase	Period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR (mm)	*CWR (mm)
Sowing – Emergence	17-11-05 to 30-11-05	14	50.4	53.2	15.12	15.96
Emergence– Third leaf	1-12-05 to 25-12-05	25	62.5	67.5	48.75	52.65
Third leaf– Tillering	26-12-05 to 20-1-06	26	52	65	48.96	61.2
Tillering– Shooting	21-1-06 to 31-1-06	11	22	27.5	21.78	27.225
Shooting– Heading	1-2-06 to 5-02-06	5	18	17	17.1	16.15
Heading– Flowering	6-2-06 to 17-2-06	10	43.2	40.8	43.2	40.8
Flowering– Milk maturity	18-2-06 to 24-02-06	7	25.2	23.8	25.2	23.8
Milk maturity– Wax maturity	25-02-06 to 6-3-06	10	35.4	40.6	35.4	40.6
Wax maturity – Full maturity	7-3-06 to 16-3-06	10	35	45	35	45
Sowing to Full maturity	17-11-05 to 16-03-2006	118	343.7	380.4	290.51	323.385

*Normals based on 1981-2010 data.

2.9.3 Crop Water Requirement during the Rabi Season 2006-07 in Tandojam

Crop water requirement of wheat crop was observed mostly normal to below normal during most of the crop growth (Fig 73 & Table 2.22).

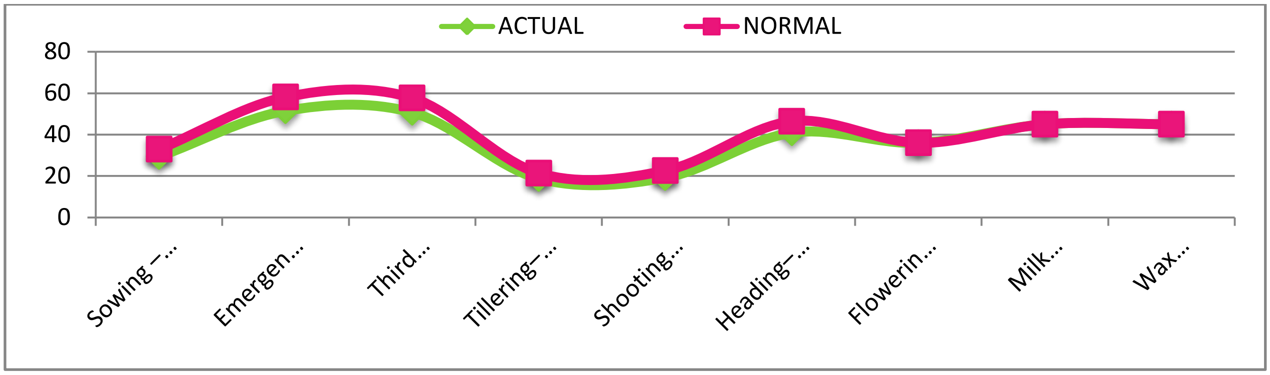


Figure 73: Comparison of CWR with Normal values during the crop life during 2006-07.

Table 2.22: Crop Water Requirement (CWR) During Crop Life in 2006-07

Inter-phase	Period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR (mm)	*CWR (mm)
Sowing – Emergence	28-11-06 to 14-12-06	17	44.4	49.2	29.45	32.90
Emergence– Third leaf	15-12-06 to 9-1-07	26	60.6	68.4	51.42	58.07
Third leaf– Tillering	10-1-07 to 1-02-07	23	51.3	58.4	50.68	57.68
Tillering– Shooting	2-02-07 to 10-02-07	9	19.8	22.5	18.81	21.37
Shooting– Heading	11-2-07 to 17-2-07	7	20.3	23.8	19.29	22.61
Heading– Flowering	18-02-07 to 2-3-07	13	40.9	46.4	40.9	46.4
Flowering– Milk maturity	3-3-09 to 10-03-07	8	36	36	36	36
Milk – Wax maturity	11-03-09 to 20-03-07	10	45	45	45	45
Wax – Full maturity	21-03-09 to 30-03-07	10	45	45	45	45
Sowing to Full maturity	28-11-06 to 26-3-07	123	363.3	394.7	336.55	365

*Normals based on 1981-2010 data.

2.9.4 Crop Water Requirement during the Rabi Season 2006-07 in Tandojam

Crop water requirement of during the season was observed normal to above normal during sowing-emergence stage and shooting to maturity stages. Whereas it remained below normal during remaining vegetative stages from emergence to shooting stages Fig 2.74 & Table 2.23).

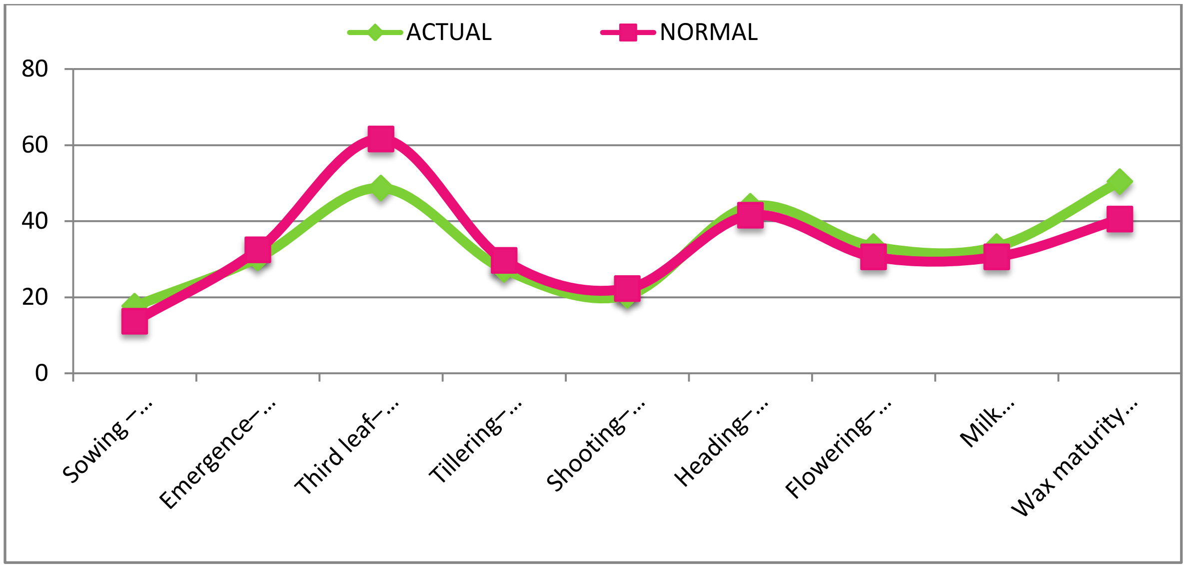


Figure 2.74: Comparison of CWR with Normal values during Rabi Crop 2007-08.

Table 2.23: Crop Water Requirement (CWR) During Crop Life during 2007-08

Inter-phase	Period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Sowing – Emergence	9-11-07 to 20-11-07	12	58.8	45.6	17.64	13.68
Emergence– Third leaf	21-11-07 to 10-12-07	20	69	65	30.3	32.46
Third leaf– Tillering	11-12-07 to 7-01-08	28	58.1	74.2	48.699	61.551
Tillering– Shooting	8-01-08 to 19-01-08	12	27.6	30	27.324	29.7
Shooting– Heading	20-01-08 to 28-01-08	9	20.7	22.5	20.493	22.275
Heading– Flowering	29-01-08 to 10-02-08	13	43.9	41.5	43.9	41.5
Flowering– Milk maturity	11-02-08 to 19-02-08	9	33.3	30.6	33.3	30.6
Milk maturity– Wax maturity	20-02-08 to 28-02-08	9	33.3	30.6	33.3	30.6
Wax maturity – Full maturity	1-03-08 to 28-03-08	9	50.4	40.5	50.4	40.5
Sowing to Full maturity	9-11-2007 to 15-03-2008	121	395.1	380.5	305.356	302.866

*Normals based on 1981-2010 data

2.9.5 Crop Water Requirement during the Rabi Season 2008-09 in Tandojam

Crop water requirement of wheat crop was observed normal to below normal during the crop growth (Fig 2.75 & Table 2.24) due to in time rainfall at required intervals and normal to below normal temperature observed during crop's life.

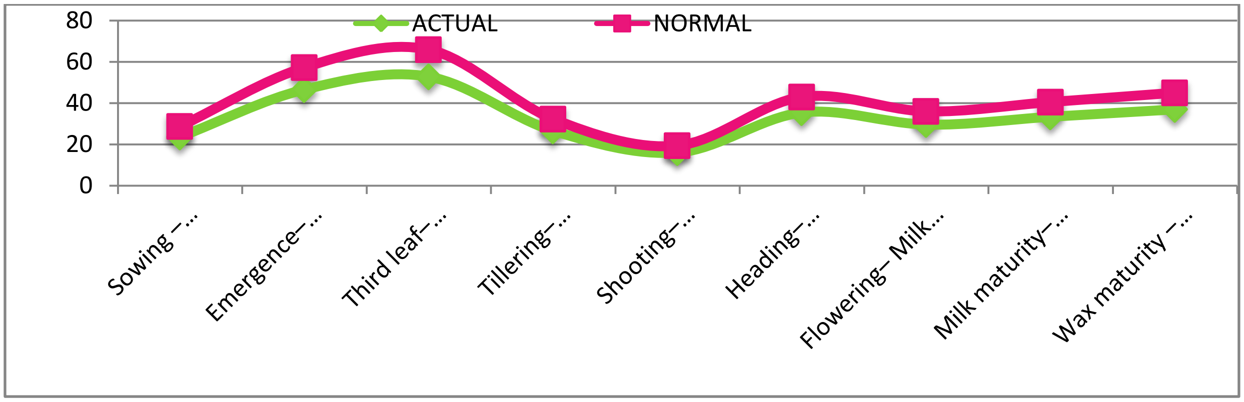


Figure 2.75: Comparison of CWR with Normal values during the crop life 2008-09.

Table 2.24: Crop Water Requirement (CWR) During Crop Life in 2008-09

Inter-phase	Period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR (mm)	*CWR (mm)
Sowing – Emergence	28-11-08 to 12-12-08	15	36.3	43.8	23.6	28.7
Emergence– Third leaf	13-12-08 to 7-1-09	26	55.8	68.8	46.5	57.3
Third leaf– Tillering	8-1-09 to 2-02-09	26	53.6	66.8	52.8	65.9
Tillering– Shooting	3-02-09 to 12-02-09	10	28	34	26.6	32.3
Shooting– Heading	13-2-09 to 18-2-09	6	16.8	20.4	16.0	19.4
Heading– Flowering	19-02-09 to 2-3-09	12	35.4	43	35.4	43.0
Flowering– Milk maturity	3-3-09 to 10-03-09	8	29.6	36	29.6	36.0
Milk maturity– Wax maturity	11-03-09 to 19-03-09	9	33.3	40.5	33.3	40.5
Wax maturity – Full maturity	20-03-09 to 29-03-09	10	37	45	37.0	45.0
Sowing to Full maturity	28-11-08 to 29-3-09	122	325.8	398.3	300.7	368.1

*Normals based on 1981-2010 data.

2.9.6 Crop Water Requirement during the Rabi Season 2009-10 in Tandojam

Crop water requirement of wheat crop was observed mostly normal to below normal during most of the crop growth (Fig 2.76& Table 2.25). However it remained above normal during wax-full maturity stage in the month of March due to above normal rise in mean daily/day time temperature. But in time supply of irrigated water fulfilled crop water demand, which resulted above normal crop growth and final yield.

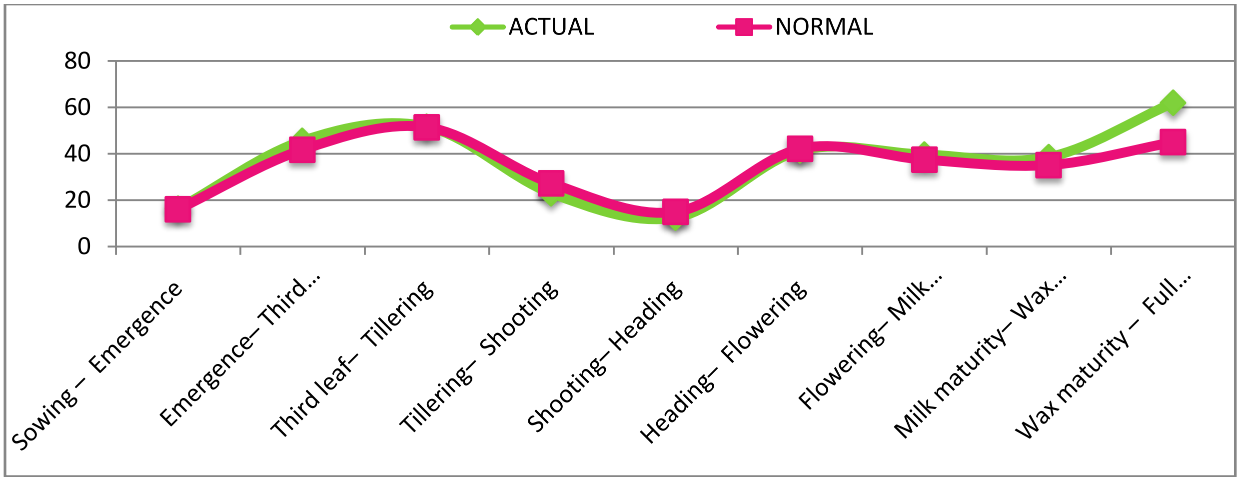


Figure 2.76: comparison of CWR with Normal values during the crop life 2009-10.

Table 2.25: Crop Water Requirement (CWR) During Crop Life in 2009-10

Inter-phase	Period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR (mm)	*CWR (mm)
Sowing – Emergence	10-11-09 to 23-11-09	14	54.6	53.2	16.4	16.0
Emergence– Third leaf	24-11-09 to 16-12-09	23	75.3	69.8	45.6	41.7
Third leaf– Tillering	17-12-09to 08-01-10	23	61.8	60.5	51.7	51.4
Tillering– Shooting	09-01-10 to 19-01-10	11	23.1	27.5	22.9	27.2
Shooting– Heading	20-01-10 to 25-01-10	06	12.6	15	12.5	14.9
Heading– Flowering	26-01-10 to 08-02-10	14	41.4	42.2	41.4	42.2
Flowering– Milk maturity	09-02-10 to 19-02-10	11	39.6	37.4	39.6	37.4
Milk maturity– Wax maturity	20-02-10 to 01-03-10	10	38.6	35.1	38.6	35.1
Wax maturity – Full maturity	02-03-10 to 11-03-10	10	62	45	62	45.0
Sowing to Full maturity	10-11-09 to 11-03-10	122	409	385.7	330.7	310.8

*Normals based on 1981-2010 data.

2.9.7 Crop Water Requirement during the Rabi Season 2010-11 in Tandojam

Crop water requirement was observed below normal throughout the crop growth. It means that crop growth did not suffer in any phase due to no sharp rise in crop water demand. Thus the available irrigated and rain water fully satisfied moisture requirement of the crop, which resulted above normal crop growth and final yield.

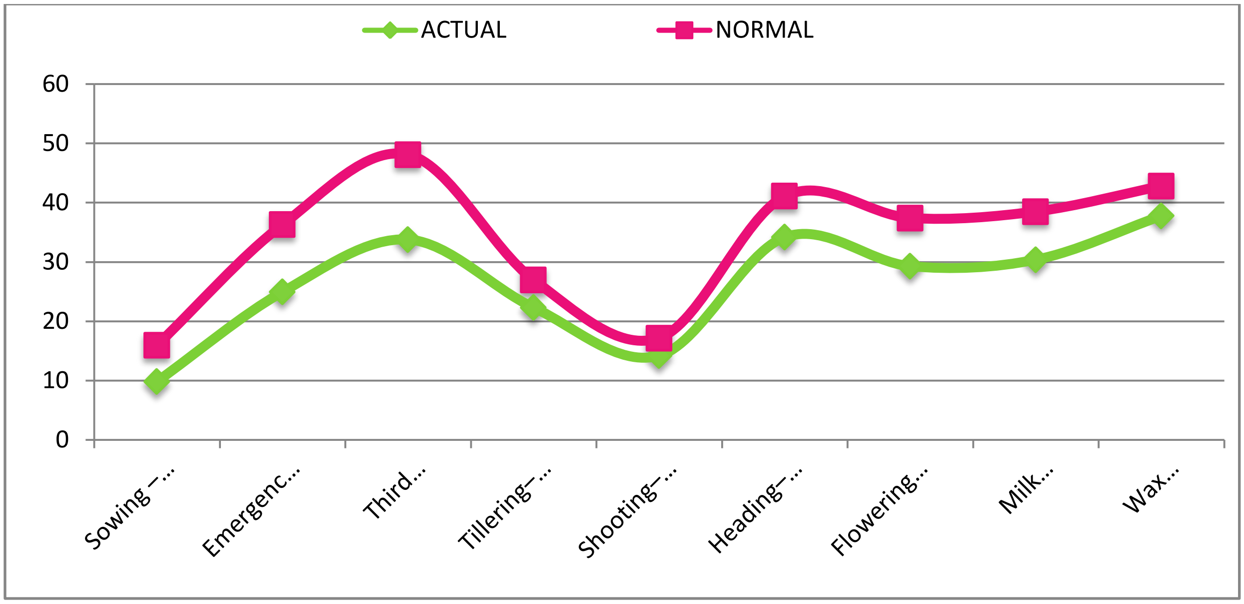


Figure 2.77: Comparison of CWR with Normal values during Rabi Crop 2010-11.

Table 2.26: Crop Water Requirement (CWR) During Crop Life during 2010-11

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Sowing – Emergence	06-11-10 to 19-11-10	14	32.8	53.2	9.84	15.96
Emergence– Third leaf	20-11-10 to 11-12-10	22	48.4	71.5	24.97	36.3
Third leaf– Tillering	12-12-10 to 02-01-11	22	42.2	59	33.8	48.1
Tillering– Shooting	03-01-11 to 13-01-11	11	22.8	27.5	22.3	26.95
Shooting– Heading	14-01-11 to 20-01-11	07	14.5	17.5	14.2	17.15
Heading– Flowering	21-01-11 to 04-02-11	15	34.2	41.1	34.2	41.1
Flowering– Milk maturity	05-02-11 to 15-02-11	11	29.3	37.4	29.3	37.4
Milk maturity– Wax maturity	16-02-11 to 26-02-11	11	30.4	38.5	30.4	38.5
Wax maturity – Full maturity	27-02-11 to 08-03-11	10	37.8	42.8	37.8	42.8
Sowing to Full maturity	06-11-10 to 08-03-11	123	292.4	388.5	236.8	304.3

*Normals based on 1981-2010 data.

Chapter 3

Results and Discussion

3.1 Crop Variety TD-1

Crop variety TD-1 is one of the most cultivated/productive varieties of wheat, cultivated in lower Sindh. The variety was cultivated for four years (2005-06, 2006-07, 2008-09 and 2009-10) during the period 2005-06 to 2010-11. TJ-83 is also one of the recommended wheat varieties, which was cultivated for two years (2007-08 and 2010-11) in the experimental field of Plant Physiological Section of Agriculture Research Institute Tandojam. No viral, pest or any other disease was reported during the crop growing period.

Table 3.1: Brief Summary of the crops cultivated 2005-06 to 2010-11

Crop Variety/ Season	Date of sowing and harvesting	Quantity of seed per acre(kg)	Fertilizer added per acre	Total days (sowing to full maturity)	No. of irrigations	yield per hectare (kg)	Normal to potential yield per hectare (kg)	Provincial yield per hectare (Kg)	Crop Status
TD-1 2005-06	18-11-2005 to 20-03-2006	40	1 bag DAP+2 Urea	118	4	3400	5868/6916	2947	Below Normal
TD-1 2006-07	22-11-2006 to 29-03-2007	50	1 bag DAP+2 Urea	123	5	5230	5868/6916	3471	Near to Normal
TJ-83 2007-08	9-11-2007 to 20-03-2008	50	1 bag DAP+2 Urea	121	5	3000	3700/4000	3440	Near to Normal
TD-1 2008-09	28-11-2008 to 31-03-2009	50	1 bag DAP+2 Urea	122	4	5850	5868/6916	3434	Normal
TD-1 2009-10	10-11-2009 to 15-3-2010	60	1 bag DAP+2.5 Urea	122	6	6150	5868/6916	3601	Above Normal
TJ-83 2010-11	6-11-2010 to 15-3-2011	60	1 bag DAP+2.5 Urea	123	6	3950	3700/4000	N/A	Above Normal

Keeping all the weather related constraints, which have been explained in Chapter-3(Materials and Methods) and some other factors i.e. time of sowing, fertilizer intake, amount of seed cultivated per acre, irrigation and weedicide operations performed on each crop in mind. We discuss each crop season and then try to find all possible causes that have affected crop’s growth and its yield.

According to Table 4.51, the crop with lowest yield obtained was cultivated during Rabi season of 2005-06 and the crop with highest yield was obtained in 2009-10. Whereas during 2006-07, near to normal or satisfactory yield was obtained and during 2008-09 normal or a bumper crop was obtained.

During the crop season 2005-06, the crop was cultivated in time (18 November). Amount of seed cultivated per acre was 40 kg whereas for normal or good crop yield, 50-60 kg seed should be added to the field. Fertilizer intake was 1 bag DAP and 2 bags Urea. This amount is said to be enough for a better yield. Rainfall i.e. weather remained dry during most of the crop period and irrigation water during the season (only four times) was not enough to meet the crop water requirement (CWR). As a result moisture content of soil and atmosphere remained deficient during early growth and grain formation stages in the months of November, February and March. During full maturity in the month of March, 50 mm rainfall reported which badly affected the crop causing reduction in final yield. Temperature regime remained below normal for most of the crop's period. But due to abnormal rise of day time and soil moisture temperature up to 4^0C during early grain formation stages (wax and milk maturity stages) in February, CWR raised above long time normal during early maturity stages in February and due to early consumption of required heat units, grain size also reduced. Thus below normal yield with shriveled grain was obtained due to the combined impact of several factors. The crop consumed 2334 heat units in 118 days from sowing to full maturity.

During the crop season 2006-07, seed added to the field was 50kg with normal fertilizer intake of 1 bag DAP and 2 bags Urea. During the whole crop season, good rain received at proper time and in sufficient amount. Rain amounting 13 mm was reported soon after the germination on 3rd and 4th of December, 3.5mm on 10th of February during shooting and 32.0mm rain on 12th March during milk and wax maturity stages. Irrigation water was added 5 times during crop's life. Temperature regime mostly remained normal to below normal during crop's growth. In time rainfall and irrigation water produced satisfactory air and soil moisture conditions for satisfactory crop growth. In spite of no weedicide operations, favorable weather conditions and other factors resulted in satisfactory or near to normal yield. The crop consumed 2377 heat units in 123 days from sowing to full maturity.

During the crop season of 2007-08, in time sowing, normal intake of seed and fertilizer, 5 times irrigation and satisfactory rainfall during crop season favored satisfactory crop growth. But due to rising atmospheric and soil temperature regime during early growth and maturity stages produced moisture deficiency affecting negatively crop growth. No operation against weeds also negatively affected crop growth and reduction in final yield. The combined impact of all these factors resulted near to normal or satisfactory yield during the crop season of 2007-08. Crop water requirement was observed mostly normal to below normal during most of the crop life. The crop consumed 2356 heat units in 121 days from sowing to full maturity.

During the crop season of 2008-09, 04 times irrigation and satisfactory rainfall and normal to below normal temperature during crop season produced favorable air and soil condition, below normal and below average CWR for satisfactory growth with normal fertilizer intake and normal amount of seed added to the field, which resulted in normal or bumper crop yield. The crop consumed 2382 heat units in 122 days from sowing to full maturity

During the crop season 2009-10, per acre seed amounted 60 kg and fertilizer used was 1bag DAP and 2.5 bags of Urea. Although weather remained mostly dry during crop's period but due to in time irrigation, crop did not experience moisture or water deficiency throughout its life cycle. Excess of weeds also play important role in yield's reduction as weeds consume considerable amount of moisture and other soil nutrients and negatively affect crop's growth at the same time. But this issue can be resolved by proper and timely use of recommended varieties of weedicides. During 2009-10 weedicides operations against broad leaf weeds were performed, which also reinforced crop's growth and crop's production. The crop consumed 2333 heat units in 122 days and was cultivated during normal time of sowing (10 November). All these factors along with below normal CWR resulted into a bumper crop yield during 2009-10.

During the crop season of 2010-11, in time sowing (6 November), above normal intake of seed (60 kg per acre) and fertilizer (1 bage DAP and 2.5 bags Urea), in time (6 times) irrigation and satisfactory rainfall, below normal air/soil temperature and crop water requirement during crop season produced best soil and atmospheric conditions for crop growth and development, which resulted above normal or bumper crop production during 2010-11. The crop consumed 2309 heat units in 124 days from sowing to full maturity.

Chapter 4

Conclusions and Suggestions

4.1 Conclusions

It is thus concluded that wheat crop growth, development and final yield during Rabi crop period 2005-06 to 2010-11 was affected both positively and negatively as result of crop to crop variation in the following meteorological and non-meteorological factors.

Supply of irrigation water, in time and required amount of fertilizer doze, timing and amount of rainfall, day time temperature, weeds removing operations, pre sowing practices on field and so on.

During the crop period of 6 years, 2005-06 to 2010-11, the yield obtained was satisfactory/near to normal yield for the seasons 2006-07, 2007-08; unsatisfactory or below normal for the season 2005-06 and bumper crop, normal to above normal yield, was obtained for three years, 2008-09 to 2010-11. The variation in the yield was due to the combined effect of meteorological and non-meteorological factors including sharp rise in day time temperature especially during grain formation stages (2005-06), improper supply of irrigation and rain water (2005-06), no weeds operation (for most of the years), less amount of seeds added per acre (2005-06). Both the crop variets TD-1 and TJ-83 has shown better results in different growing conditions.

Wheat crop heat units consumption may vary variety to variety and year to year due to any pest/viral attack, varying amount of weeds growth in different years and varying amount of Phosphorus and Nitrogen fertilizer added to the crop each year. On average the crop consumed 2349 heat units in 122 days from sowing to full maturity. Normally wheat crop consume these heat units in 120 days if it is cultivated up to 15th of November in lower Sindh.

4.2 Recommendations and Suggestions

Keeping above results and conclusions, following recommendations/suggestions are proposed for farmers and related personals to enhance wheat crop yield in lower Sindh as well as all over Pakistan.

1 – Farmers generally plant wheat late in rice-wheat, sugarcane-wheat, and cotton-wheat areas due to late harvesting of these kharif crops which results in drastic low yields because the crop is exposed to heat stress and rising CWR at grain formation stages (milk and wax maturity stages) leading to the formation of shriveled grain. To achieve good yield, wheat sowing should be carried in time, suiTable 3. crop sowing period in lower Sindh is observed 1-15 of November.

2– Wheat plant water requirement is maximum during flowering and early grain formation stages (milk and wax maturity stages) followed by vegetative stages. Therefore farmers and policy makers should make possible the availability of irrigation water to wheat crop to get optimum crop yield.

3– Farmers may be advised to be in contact with local/Federal Agricultural Departments and Pakistan Meteorological Department throughout crop's life, especially at the time of sowing, adding fertilizers to crop and before irrigation. It will help the farmers get in time advices to deal in better way with any present or coming drought/ water stress condition and to get best results of fertilizer and irrigated water used. Weather information is especially very crucial for those areas where crops are partially/fully irrigated through tube wells

4– Recommended amount of high yielding seed resistant to diseases must be used.

5– Care must be taken to check the pre and post-harvest losses of wheat.

References

Agriculture times Islamabad, (2011). October edition

Chatrath, R. , B. Mishra, G. O. Ferrara, S. K. Singh and A. K. Joshi. (2007). Challenges to wheat production in South Asia, available on line;
http://www.springerlink.com/content/vtt6162504468m36/
http://www.springerlink.com/content/vtt6162504468m36/

Chaudhry, Q.Z. and G. Rasul, (2004). Agroclimatic Classification of Pakistan, *Science Vision.* Vol.9, No.1-2 & 3-4, (July-Dec, 2003 &Jan-Jun, 2004), pp 59.

C. Kirda, Deficit irrigation scheduling based on plant growth stages showing water stress tolerance , an FAO technical paper on irrigation, available on line;
http://www.fao.org/docrep/004/Y3655E/y3655e03.htm

Climatic Normals of Pakistan (1971-2000), (2005). Pakistan Meteorological Department. Karachi

Curtis, B. C., Wheat in the world, an FAO technical paper on wheat, available on line;
http://www.fao.org/docrep/006/y4011e/y4011e04.htm

Economic Survey of Pakistan, (2009). Ministry of Finance, Government of Pakistan, Islamabad.

FAO Irrigation and Drainage Paper 33.

Fowler, D. B. (2002). Growth Stages of Wheat, Chapter 10,
http://www.usask.ca/agriculture/plantsci/winter_cereals/index.php

Hashmi, F. (1989). Agrometeorology of Pakistan.

Kazmi, D. H. (2009). Investigation of Meteorological factors affecting wheat yield in rainfed areas of Potohar region, an MS dissertation, COMSATS, Islamabad.

Khoso, A. W. (1977). Crops of Sindh, published by the author, pp 181.

Mavi, H. S. and Graeme J. T. (2005). Agrometeorology; principals and applications of climate studies in agriculture, international book distributing company, Lucknow, India.

Naheed, G. (2009). Water requirement of Wheat crop in Pakistan, an MS dissertation, COMSATS, Islamabad.

Panhwar, F. (2005). Wheat Cultivation in Sindh Pakistan, Digitalverlag GmbH, Germany.

Rasul. G., (1993). Water requirement of wheat crop in Pakistan. *Journals of energy and applied sciences*, Vol.12, No.2, July-Dec.

Shamshad, K.M. (1988). Meteorology of Pakistan, Royal Book Agency, Karachi, Pakistan.

USDA Foreign Agriculture Service report. (2010).