An Analysis of Weather and Cotton Crop Development in Lower Sindh (Tandojam) (2007-2011)

by

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Summary

This study has been carried out to investigate the impact of day to day changes in the meteorological parameters like rainfall, air and soil temperature; air and soil moisture on plant growth and development during each phenological stage and on final yield of cotton crop. For this purpose both Meteorological and phenological observations along with soil data have been monitored at different phenological stages of cotton crop, cultivated in the field of Plant Physiology Section of Agricultural Research Institute Tandojam (Lower Sindh) during the Kharif Season 2007 to 2011. Beside this some other factors e.g., time of sowing, fertilizer intake, and weeds removing operations and supplied irrigated water have also been studied. The crop on average accumulated 4353 heat units in 138 days during its life cycle from emergence to maturity. Water requirement was fulfilled through flood irrigation onwards from early growth up to maturity stage. Crop growth and production varied during this period mainly due to time of sowing, irrigation, in time use of chemicals against weeds and pest/viral attacks, variation in rainfall during each crop and heavy rain spells from flowering to maturity stages. Day time rise in temperature and so on. This study is based upon data of two cultivars in five years span. Therefore the study will be much fruitful in future to narrow the gap between present yield obtained and potential yield of this cultivar, being cultivated in Tandojam and other cotton growing areas of lower Sindh

Chapter 1

1. Introduction

This study is based upon field observations of cotton 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 Kharif seasons 2007-2011. The study permits the cotton varieties Sindh-1 and Niab-78 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 has a variable climate, ranging from arid (30-250 mm annual rainfall) in the south to humid (1000-2000 mm per year), sub-humid (500-1000 mm per year) and semi-arid (250-500 mm per year) in the north. The river Indus that originates in the north with its tributaries irrigates the most of the agricultural plains of the country. The area to the left of Indus is much affected by the neighboring arid and hot Rajasthan desert [1]. The agriculture in the major portion of upper half of the country which is mainly semi arid depends upon canal irrigation besides considerable intake of rain water also available due to monsoon weather systems. Winter rains occur due to westerly waves that penetrate into 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 satisfactory precipitation occurs both in summer and winter and agriculture is carried out without canal irrigation [2].The climate of lower half including agricultural plains of southern Punjab, Sindh and Balochistan have mostly arid climate, where annual rainfall is much less 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 extend to the southern 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 Institute Tandojam, located in the lower parts of Sindh, 20 km away from Hyderabad city on Mirpurkhas-Hyderabad highway. The latitude and longitude of RAMC Tandojam are 25.67ºN and 68.72ºE respectively. Total annual rainfall in lower Sindh ranges 140-160 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. Day time mean maximum and night time mean minimum temperatures gradually increase from May to June and then gradually decrease till October during Kharif Season. Analyzing the available data of Tandojam (1989 to 2011), it was observed that day time highest maximum temperature in May was recorded 47.5ºC in 2001, 2010 and 2011 each, in June it was recorded 47ºC in 2011, in July it was observed 45.2ºC in 2009, in August 41ºC in 2004 and in September it was observed40.5ºC in 2007.Night time lowest

minimum temperature was recorded 18ºC in May 2004, 19.5ºC in June 1997, 23ºC in July1998 and 2001 each and 19.6ºC in September1991 during the period 1989 to 2011. Highest amount of rainfall in May was recorded 47mm in 1991, 85.6mm in June 2010, 247mm in July 2003, 189mm in August 2011 and 338mm in September 2011. Tropical cyclones also affect monsoon rains in lower Sindh including Tandojam. The tropical cyclones that originate in Arabian Sea mostly hit the coastline of the Indian stage of Gujarat during the last 50 to 60 years in pre monsoon period from May to June. The significant tropical cyclones that hit the coastal belt of Sindh are the cyclones of 1998 and 1999. The cyclone of 1999 of category 3A that hit costal belt of Sindh in May was the most intense and destructive cyclone ever recorded in Pakistan disturbed monsoon weathers systems track over Sindh and as a result dry monsoon was observed in Sindh. Whereas the cyclone of 1998, which mainly hit Indian Gujarat and then coastal Sindh in June was comparatively weaker. But it also affected monsoon rains and below normal rains amounting only 18mm was reported in Tandojam during monsoon from July to September[3]. Crop water requirement of Cotton in lower Sindh is more than 600mm. Therefore normal to above normal crop production depends upon in time supply of irrigated water in required time.

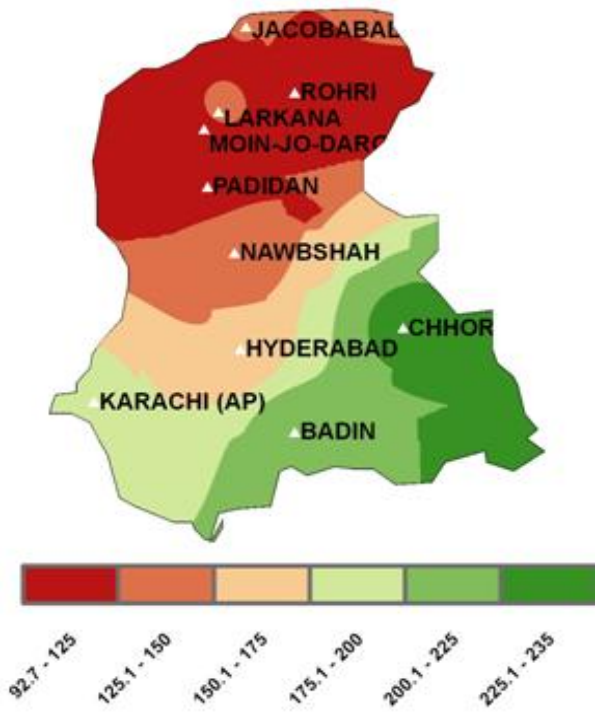

Figure 1-1: Mean Annual Rainfall (mm) of Sindh

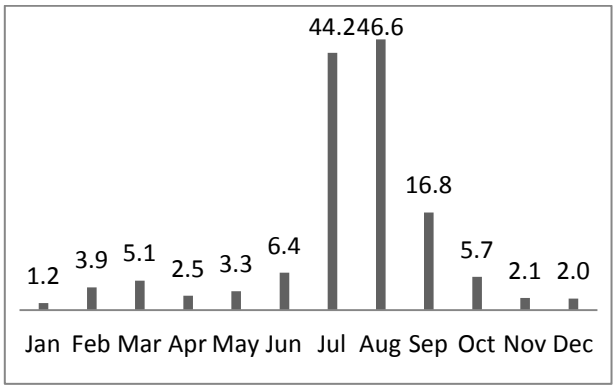

Figure 1-2: Monthly Mean Annual Rainfall (mm) of Tandojam

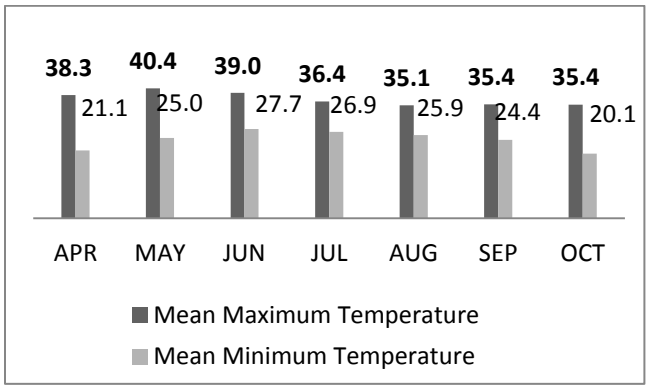

Figure 1-3: Mean daily Maximum and Minimum Temperature (ºC) of Tandojam during Kharif Season

1.2. Scope of the Study

Cotton is grown mostly in the irrigated agricultural plains of Punjab and Sindh, on the two sides of Indus canal network. Every year cotton production in Pakistan varies due to the unpredictable climate of Pakistan. Therefore every year variation in the spatial and temporal distribution of rainfall causes changes in the amount of available water for irrigated agricultural regions, which consequently brings up and down in the annual yield of cotton. Some time heavy rains along with persistent cloudy/humid conditions during monsoon season trigger to viral/pest attacks on cotton crop and also cause rapid growth of weeds in the fields and prolongs the crop period, which causes delay in sowing of next Rabi crop. Rain, just after sowing, causes decrease in the number of germinated cotton seeds. Heavy rain may damage the crop from flowering to maturity. Abnormal rise in day time temperature due to climatic variability may also raise crop water requirement at a particular phase and also may cause early completion of a phase. Therefore, in this study the impacts of variations in all weather parameters beside rainfall and temperature along with variations in soil temperature and moisture will be analyzed to understand crop growth and development throughout the crop life and their impact on final yield of the crop obtained.

1.3. Objective of the Study

- To investigate the impact of various meteorological parameters on crop growth and development in Tandojam area.
- To make an attempt for formulation of yield estimation mechanism, i.e. crop-weather model development.
- 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.

1.4. Review of Agriculture Production in Pakistan

The agriculture sector continues to be an essential component of Pakistan's economy. It currently contributes 21 percent to GDP. Agriculture generates productive employment opportunities for 45 percent of the country's labour force and 60 percent of the rural population depends upon this sector for its livelihood. It has a vital role in ensuring food security, generating overall economic growth, reducing poverty and the transforming towards industrialization.

Pakistan is an agrarian country whose population and economy directly or indirectly (70% directly and 16% indirectly) depends upon agriculture. The importance of agriculture to the economy is seen in three ways, firstly it provides food to consumers and fibbers for domestic industry, secondly it is the main source of foreign exchange earnings and lastly it provides market for industrial goods. Agriculture contributes 21% to country's Gross Domestic Product (GDP). About 60 % of the rural population depends on agriculture, as it employs over 45 % of the labor force. Within the agricultural sector, the contribution from crop production is about 42 % while livestock contributes 55 %. Therefore any change in agricultural productivity sends a ripple effect throughout the rural population of Pakistan. Thus rapid agricultural growth can stimulate and sustain the pace of industrial growth, setting into motion a mutually reinforcing process of sustained economic growth in the country [4].

The Economic development of Sindh largely depends on the progress and growth of Agriculture Sector. The province contributes significantly towards overall national agriculture production in major crops: 32% in National Rice Production, 24% in National Sugarcane Production, 12% in National wheat Production and 21% in National Cotton Production [5].

1.5. Cotton Production in Pakistan and Sindh

Cotton is an important cash crop for Pakistan known as "white gold". It accounts for 8.2 percent of the value added share in agriculture and about 3.2 percent to GDP, around two thirds of the country's export earnings are from the cotton by-products which add over $2.5 billion to the national economy. Hundreds of ginning factories and textile mills in the country mainly depend on cotton. Life of millions of farmers is dependent on this crop, in addition to millions of people employed along the entire cotton value chain, from weaving to textile and garment exports. The area under the cultivation has decreased from 3million hectares in 2007 to 2.8million hectares in 2007. Whereas yield per acre increased from 649kg in 2007 to 815kg in 2011-12. Well-researched BT cotton seed, proper crop-related information to growers for usage of fertilizer and pesticides and appropriate water availability in major crop-growing areas in Punjab and Sindh increased the production beside torrential rains and flash flooding in cotton belt of Sindh and Punjab in 2010 and 2011 [4].

In Sindh cotton is cultivated on both sides of Indus River. The crop is mainly grown in Hyderabad and Sukkar division. The crop is planted in April/May and picking starts in August. The crop is harvested in October. Total contribution of Sindh is about 21% in total cotton production of Pakistan. The fertile land of Sindh dominates in per acre yield across the cotton belt followed by Punjab. Whereas Punjab dominates in area and total annual production in the country. During the last five years (2006-2010) cultivated area of Sindh reduced from 607400hectares to 457000hectares but per acre yield increased from 710kg to 1354kg. The crop production in 2010 set a new record. Bumper crop was also reported in 2011. But the crop was damaged/affected in some areas due to flash flooding/stagnant water during monsoon. Due to which yield was reduced in some areas including Tandojam [6].

Chapter 2

2. Materials and Method

This study is based upon field observations of two recommended varieties Sindh-1 and Niab-78 of cotton crop planted in the experimental field of plant physiology section of Sindh Agriculture Research Institute Tandojam in lower Sindh during Kharif seasons 2007-2011. The crop variety Sindh-1 was cultivated for four years and Niab-78 for one year.

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.

Table 2-1: Observed Meteorological Parameters

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

2.1. Phenological Observations during Crop Growth

A sound understanding of plant growth and development is an essential element of efficient economic cotton management system. The impact of heat, drought, diseases, insects, and weeds can be more accurately predicted with a clear picture of the relationship between growth stage and plant response to stress. The optimum timing of fertilizer, irrigation, herbicide, insecticide, and fungicide applications are also best determined by crop growth or Phenological stage rather than calendar date [7].

2.1.1. Phenological Stages of Cotton Crop

Growth period of cotton crop consists of the following phenological stages/phases.

Germination

This phase can be distinguished by the formation of radicals. The observation of this phase begins the fourth day after planting. In each plot soil is uncovered until two seeds are noted and the number of germinated seeds is recorded.

Emergence

Emergence is distinguished by the appearance of the cotyledons above the soil surface. The beginning of phase should be recorded in AR3-3 without giving numbers. Then enough plants have emerged so that crop rows are distinguished. One meter length of one row in each plot is selected for the observation of the next phase.

Third True Leaf

The terminal bud growth between the two cotyledons (seeds leaves) produces one true leaf and continues to grow and produce more true leaves. The first two true leaves are oval shaped while the third one is spear shape. The appearance at this leaf is recorded. The number of plants in phase is given as noted in AR3-3 i.e. the number of plants in phase divided by the total number of plants in 5 meter length.

Budding

The first fruiting branch usually forms in the axil of 5th or 6th leaf (some time at the axil of third or 4th leaf). The fruit bud becomes visible to the eye, in most cases after the appearance of the 5th leaf. The bud is in the shape of a three walled pyramid. It is lighter in colour than plant leaves. This is due to the pubescence of bracket. The phase is considered established when the bud is 3-5cm in size.

Flowering

Cotton flowering starts from the base and progresses to the top of the plant. The flower lasts only one day. Therefore when counting the plants in flowering, it is necessary to include the bushes bearing the first open flowers and those with flowers already wilted.
The bud unfolded in the morning and the flower is already wilted by the evening. When the flowers open they are yellowish white in most cases. Towards the evening they turn pink, red or lilac and wilt afterward.

Boll opening

This phase is established when the opening of the top of the boll is 1cm long and the cotton lent fibers are visible through the opening. The phase is considered established even when only one boll is opened, abnormal bolls or bolls which are obviously injured usually open earlier and sometimes sideways [8].

2.1.2. Phenological Observations in the Field Selected For Cotton 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 of this crop was 4.5 acres 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.

2.2. Analysis of the Variation in Meteorological and Non-Meteorological Parameters and Their Impact on the Crop Growth and Development

In order to analyze the major causes behind variations in the crop's growth, development and yield related to varying weather and some other factors during each Phenological stage, the crop is studied and analyzed in the following manner.

2.2.1. Rainfall and Cotton Crop Growth during Kharif Season in Tandojam

Rainfall is one of the most important factors that affect annual cotton production in Pakistan. Tandojam and its surrounding areas of lower Sindh get most of its total annual rainfall (more than 80%) during Kharif season, particularly during monsoon season from July to September. But this amount is not sufficient to fulfill cotton crop water requirement in hot Kharif season. Therefore cotton crop is mainly grown under flood irrigation from Indus canal network. But monsoon rains during hot summer some time damage standing crops. Humid atmosphere during monsoon may also trigger pest attack on the crop. In addition rainfall also provides clean environmental conditions to support optimum photoperiodic activity for better biomass and grain yield [9].

During the crop season 2007, hot and dry weather reported in May and 34.4mm rain was reported in June for four days, rainfall amounting 11.4 mm was reported for 03 days in July and rainfall amounting 72.8mm for 5 days in August during flowering stage and 4mm rain for a for a single day in September, whereas dry weather is reported in October.

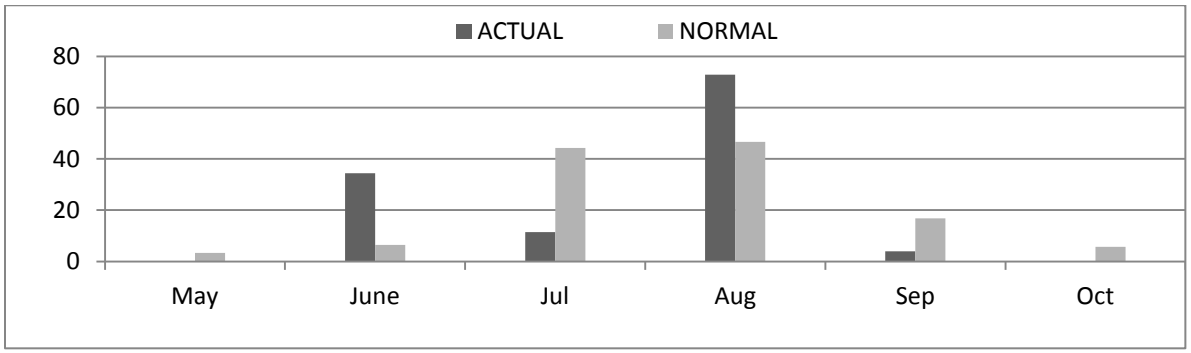

Figure 2-1: Rainfall (mm) during 2007

During the crop season 2008, hot and dry weather reported in May and 1mm rain was reported in June only for a single day, rainfall amounting 26.2mm was reported for 02days in the last of July and rainfall amounting 42.8mm for 3 days in August during boll opening stage and dry weather reported in September and October during maturity stages. Any damage to the crop was not reported during monsoon season. Rainfall reported during crop life positively supported crop growth.

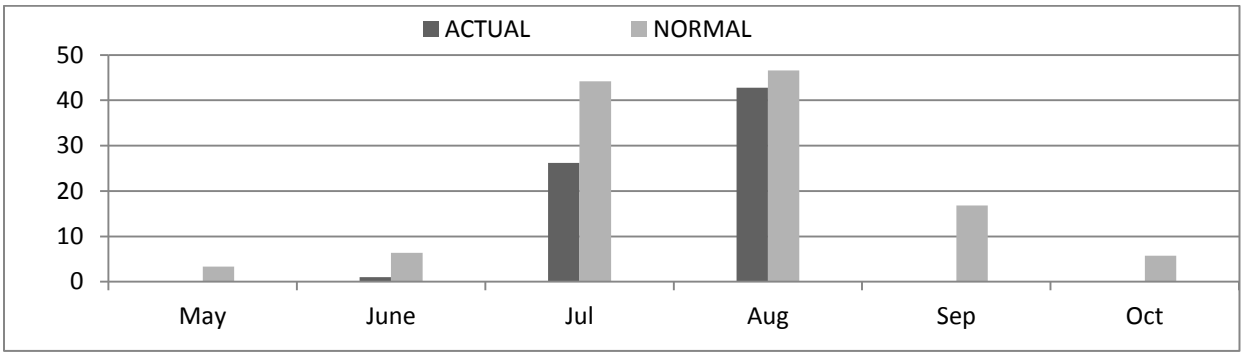

Figure 2-2: Rainfall during 2008

During the crop season 2009, hot and dry weather reported in May and 6.5mm rain was reported in June only for a single day, rainfall amounting 88.5 mm was reported for 03days in July and rainfall amounting 72mm for a single day on 31st of August during boll opening stage and 2mm rain for a single day in September. Whereas dry weather is reported in October. Overall the rainfall supported crop growth and development during crop life and no significant damage to the crop was reported during flowering/boll-opening stages in monsoon period.

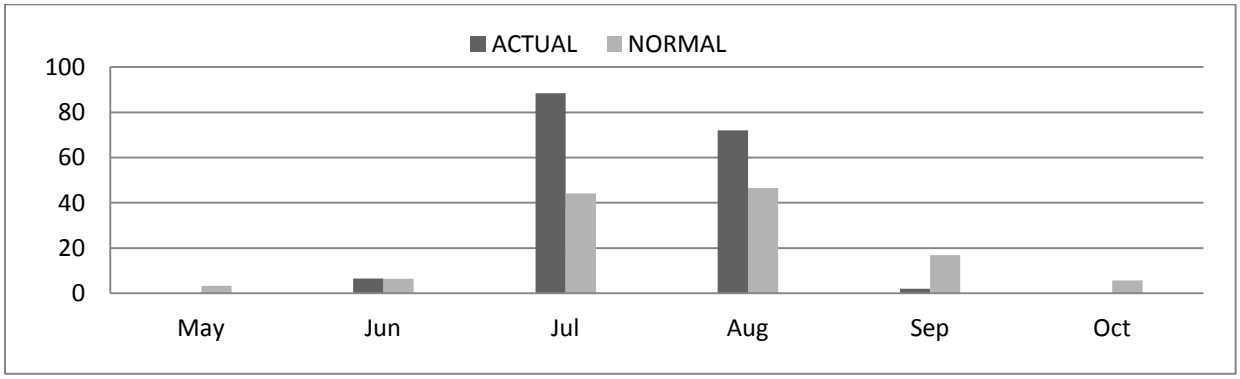

Figure 2-3: Rainfall during 2009

During the crop season 2010, hot and dry weather reported from April to May during early growing stages. In June above normal rain amounting 85.6 mm rain reported for two days, in July 39mm rain was reported for five days and, 98.6 mm for 6 days was reported in August and 13.6 mm rain was reported for a single day in September. All these rain spells promoted normal crop growth and development. No damage to the crop was reported as a result of rainfall throughout crop period.

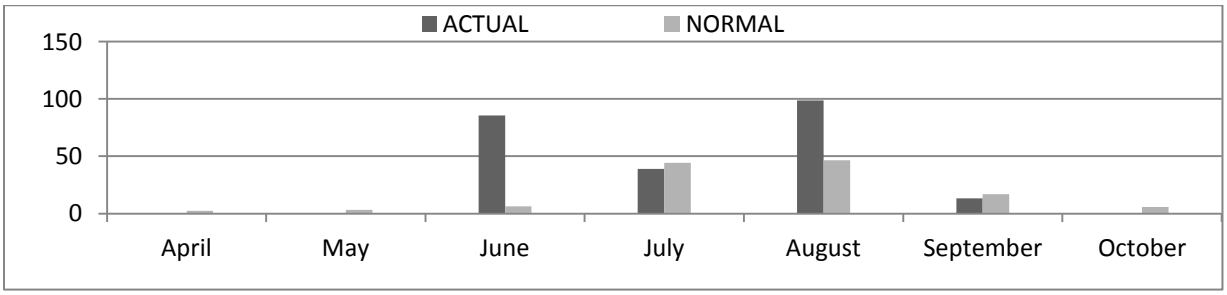

Figure 2-4: Rainfall during Kharif Season 2010

During the crop season 2011, hot and dry weather reported up to the end of July. However above normal heavy rainfall, was reported in the month of August for 8 days. In September rain

was consistently reported during its first half during boll-opening and maturity stages. During boll opening/formation stage 266 mm rainfall was recorded and during picking 121mm rain was reported. This heavy rainfall produced stagnant water in the field and negatively affected the crop growth and development.

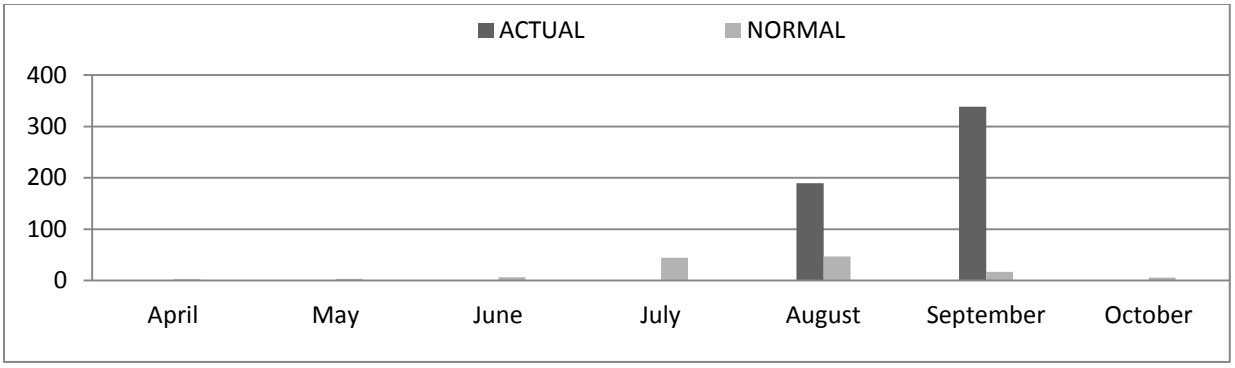

Figure 2-5: Rainfall during Kharif Season 2011

2.2.2. Irrigated Water during Crop Growth

4 to 5 times irrigation water was given to each crop during 2007 to 2011.

During 2007, 4 times irrigated water was added to the field; first irrigation was given 23 days after sowing during early growing stage of third leaf. Remaining three irrigations were given during budding, flowering and boll opening stages at the time of need.

During 2008, 5 times irrigated water was added to the field; first irrigation was given 22 days after sowing during third true leaf stage. Remaining four irrigations were given during budding, flowering and boll opening stages at the time of need.

During 2009, 4 times irrigated water was added to the field; first irrigation was given 20 days after sowing during third true leaf stage. Remaining three irrigations were given during budding, flowering and boll opening stages at the time of need.

During 2010, 3 times irrigated water was added to the field; first irrigation was given 18 days after sowing during third true leaf stage. Remaining 2 irrigations were given during budding and flowering stages at the time of need. Satisfactory rains at intervals during each Phenological stage helped in compensating crop water requirement.

During 2011, 3 times irrigated water was added to the field; first irrigation was given 22 days after sowing during third true leaf stage. Remaining two irrigations were given during budding and flowering stages. Whereas heavy rainfall accompanied with stagnant water superseded crop water requirement from boll opening to maturity and badly affected/damaged crop growth, which resulted poor crop production.

2.2.3. Air Temperature and Cotton Crop Growth during Crop Seasons 2007-2012

Air temperature is also one of the most important climatic variables that affect plant life. Plants growth is restricted to certain limits of air temperature. The main dry matter process i.e. photosynthesis is also temperature dependant [10].

The growth and maturity of cotton crop is disturbed at times by variation in day time temperature during both plant vegetative and reproductive stage. Any rise in day temperature may rise crop water requirement and may also trigger pest attack on the plant during humid monsoon period.

During the crop season of 2007, mean daily temperature was observed normal to below normal during crop life. Whereas day time maximum temperature remained normal to slightly above normal during early growing stages from May to July and remained normal to slightly above/below normal during later reproductive stages, Figure(2-7,2-8).

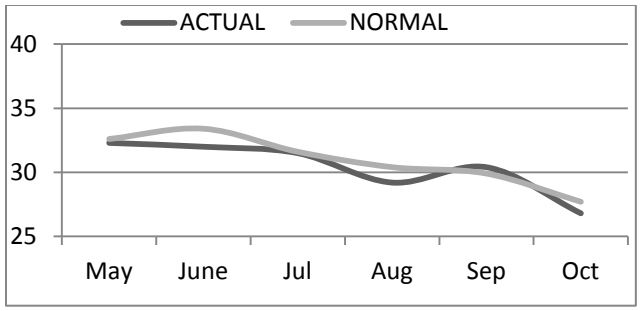

Figure 2-6: Mean Monthly Temperature during 2007

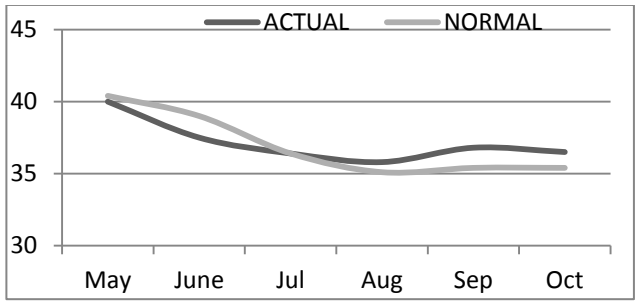

Figure 2-7: Mean Maximum Temperature during 2007

During the crop season of 2008, mean daily temperature was observed normal to below normal during most of the crop life except in the month of June during which it was observed above normal by 4^{o}C. Whereas day time maximum temperature remained normal to slightly above normal during most of the growing stages from May to end of August and remained normal to slightly above normal during later maturity stage, Figure (2-9, 2-10).

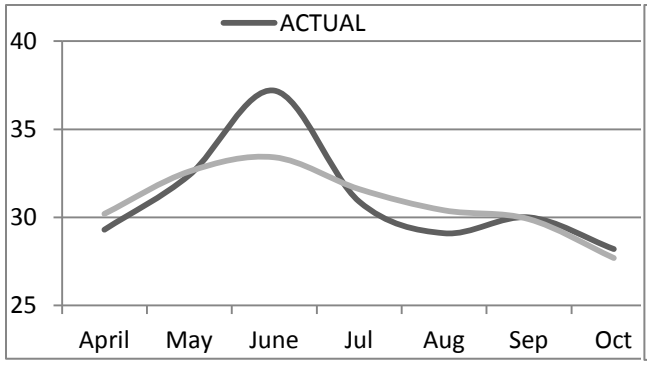

Figure 2-8: Mean Monthly Temperature during 2008

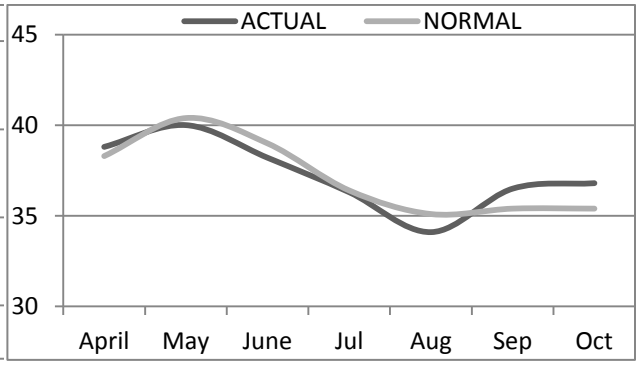

Figure 2-9: Mean Maximum Temperature during 2008

During the crop season of 2009, mean daily temperature was observed normal to below normal during crop life. Whereas day time maximum temperature remained normal to slightly above normal during early growing stages from May to July and remained normal to slightly above/below normal during later reproductive stages, Figure(2-11,2-12).

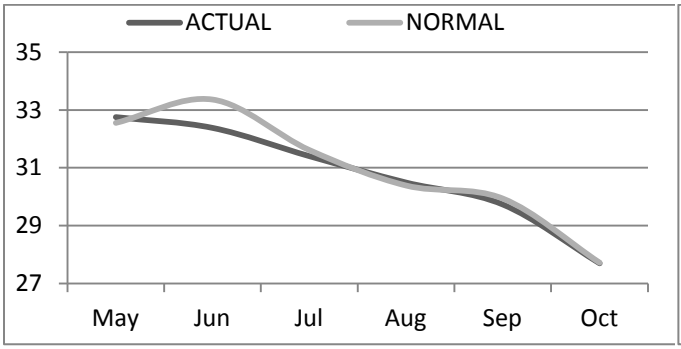

Figure 2-10: Mean Monthly Temperature during 2009

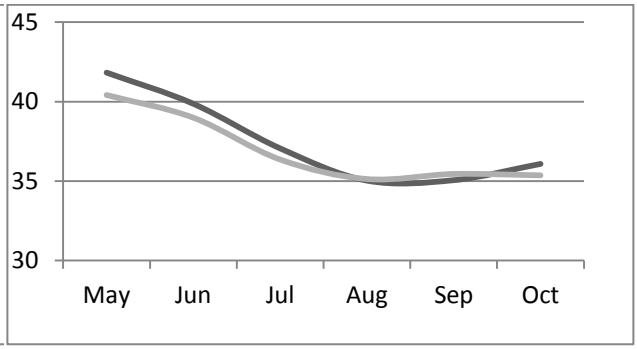

Figure2-11:Mean Maximum Temperature during 2009

During the crop season of 2010, mean daily temperature and day time maximum were observed mostly above normal during crop life, except in the month of June July and August, during which these values observed normal to below normal due to above normal rains reported in these months, Figure (2-5, 2-6).

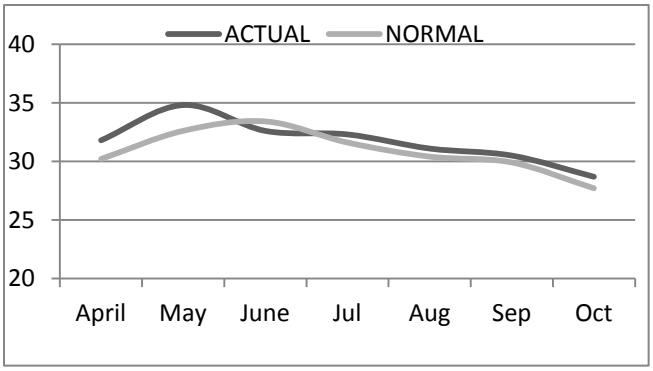

Figure 2-12: Mean Monthly Temperature during 2010

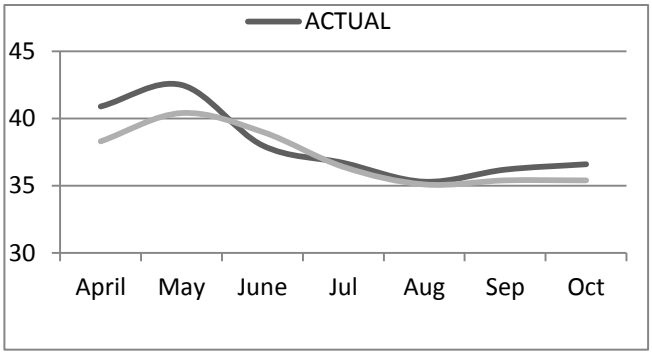

Figure 2-13: Mean Maximum Temperature during 2010

During the crop season of 2011, mean daily temperature was observed normal to below normal during most of the crop life. Whereas day time maximum temperature remained normal to above normal during early growing stages from May to June and remained normal to below normal during later reproductive stages, Figure (2-15 to 2-16). This concludes that air temperature regime was mostly favorable for crop growth and development.

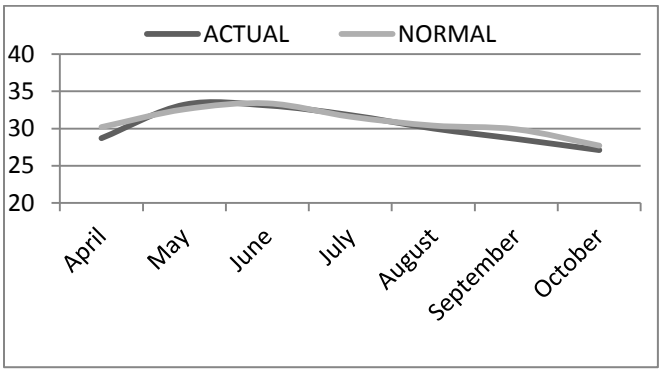

Figure 2-14: Mean Monthly Temperature during 2011

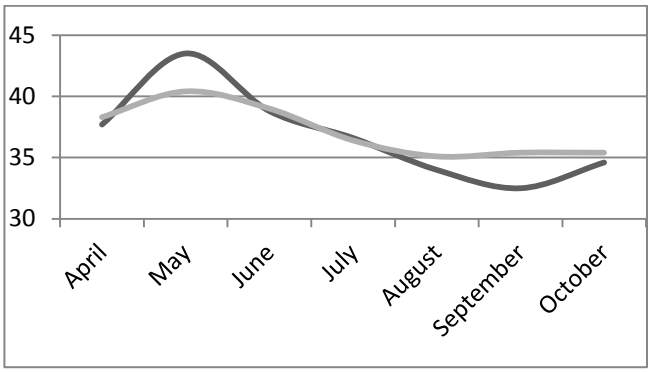

Figure2-15:Mean Maximum Temperature during 2011

2.2.4. Soil Moisture Observations 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 cotton crop varies during different growth or Phenological stages. Water or soil moisture requirement of cotton crop varies during different growth or Phenological stages. Highest amount is needed during flowering/boll opening stage followed by maturity and early vegetative stages [11].

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;

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

During the crop season 2008, from the observed soil moisture data, Figure 2-16 to Figure 2-19 depicts that soil moisture remained satisfactory during most of the crop stages due to in time irrigation and satisfactory rains during monsoon period. Slight moisture deficiency was observed during September but it did not affect the crop growth negatively. Throughout the crop life soil moisture remained more satisfactory in intermediate or major root zone and deep layers, whereas, it remained slightly deficit in shallow layers due to sensible heating of direct solar radiation. Overall condition of soil moisture was satisfactory due to satisfactory availability of irrigated water during crucial stages.

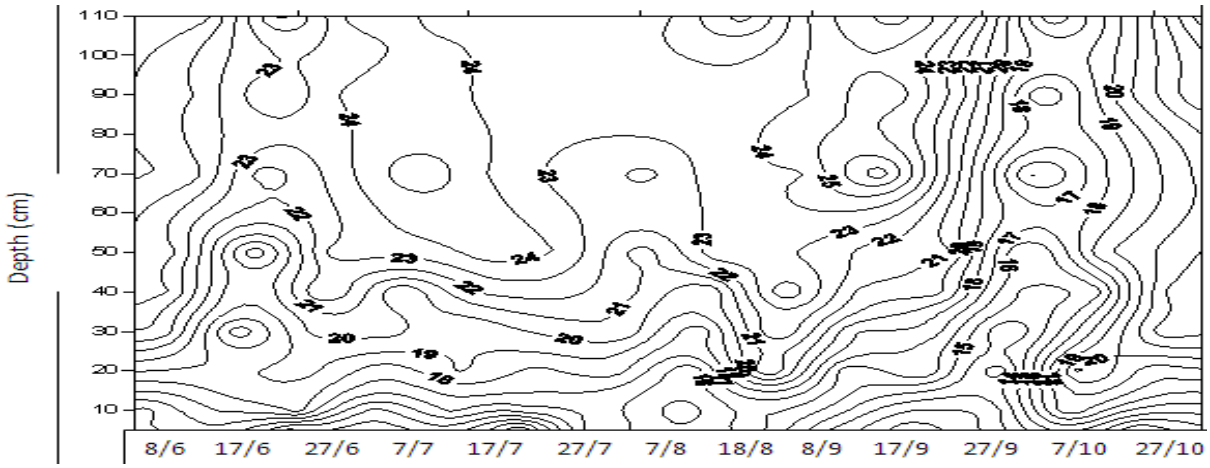

Figure 2-16: Soil moisture chrono Isopleths for Kharif Crop at Tandojam for the year 2008

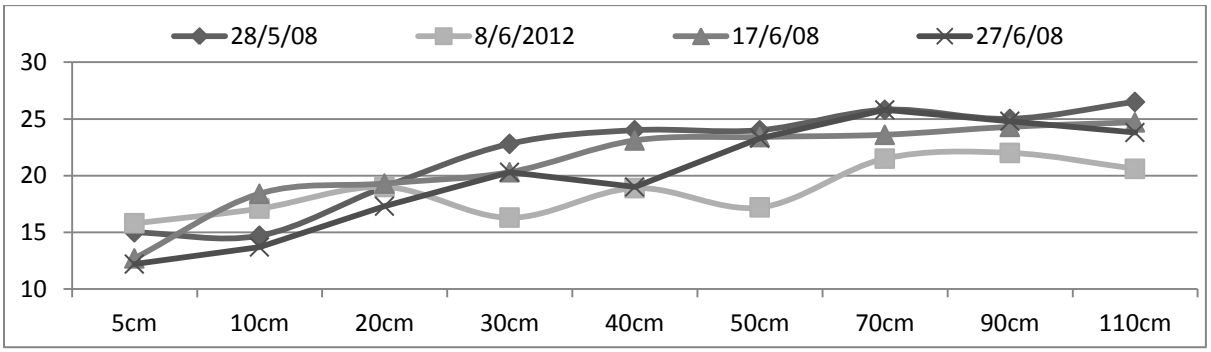

Figure 2-17: Soil moisture during May to June 2008

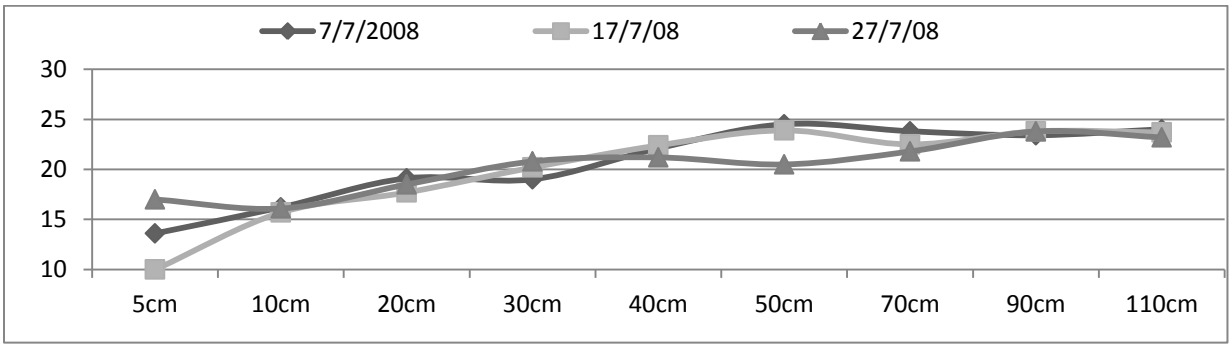

Figure 2-18: Soil moisture during July 2008

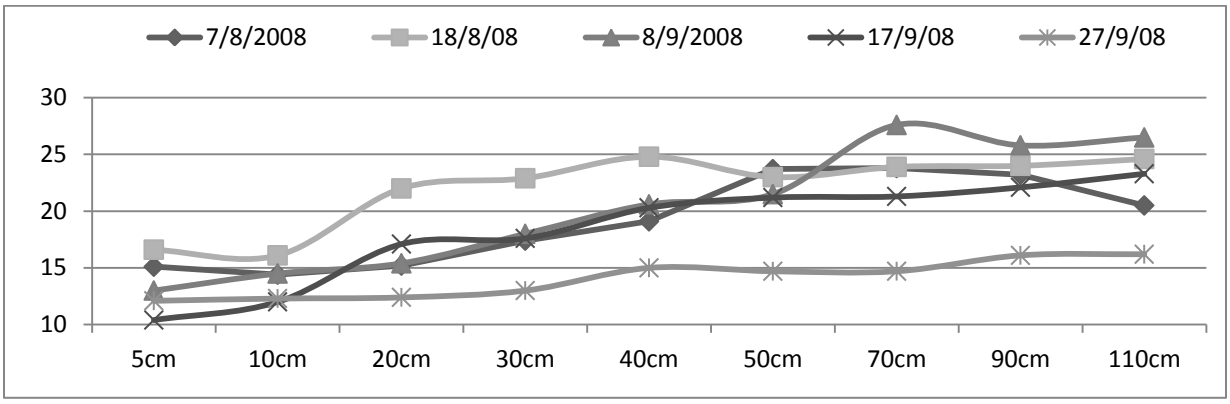

Figure 2-19: Soil moisture during Aug-Sep 2008

During the Crop Season 2009, from the observed soil moisture data, Figure 2-20 to Figure 2-23 depicts that soil moisture remained unsatisfactory during early stages due to rising temperature and dry weather in May, during flowering stage in August due to mostly dry and hot weather and during maturity stage in October. Throughout the crop life soil moisture remained more satisfactory in intermediate or major root zone and deep layers, whereas, it remained slightly deficit in shallow layers due to sensible heating of direct solar radiation. Overall condition of soil moisture was satisfactory due to satisfactory availability of irrigated water during crucial stages. However dry and hot weather at crucial stages affected crop growth to some extent especially during the most demanding phases (flowering, maturity and early growing stages).

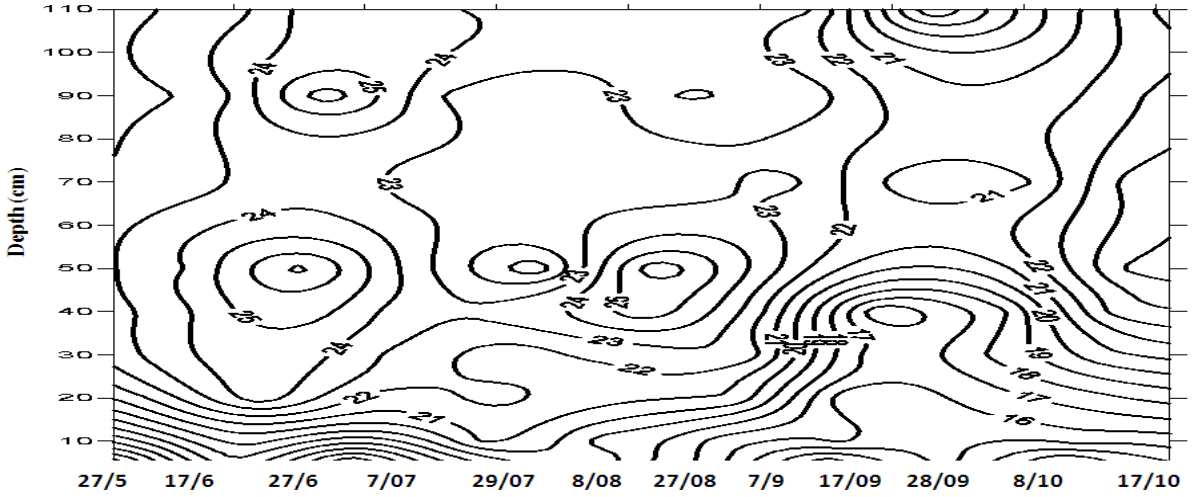

Figure 2-20: Soil moisture chrono Isopleths for Kharif Crop at Tandojam for the year 2009

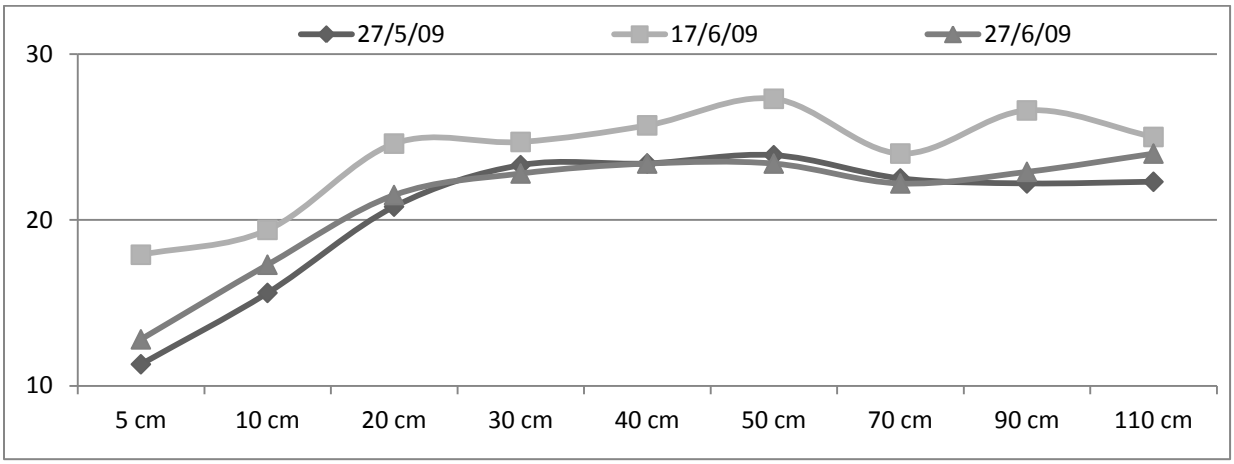

Figure 2-21: Soil moisture during May to June 2009

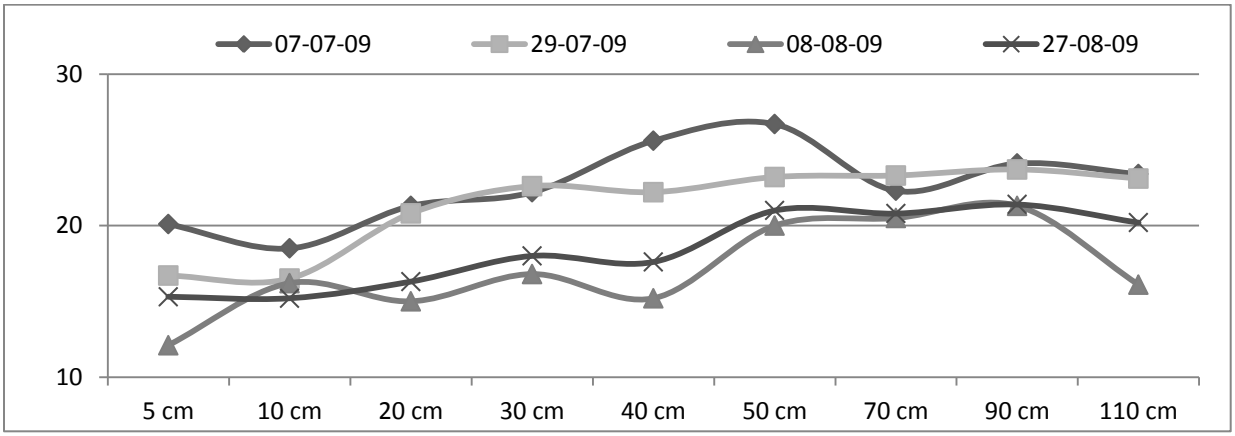

Figure 2-22: Soil moisture during Jul-Aug 2009

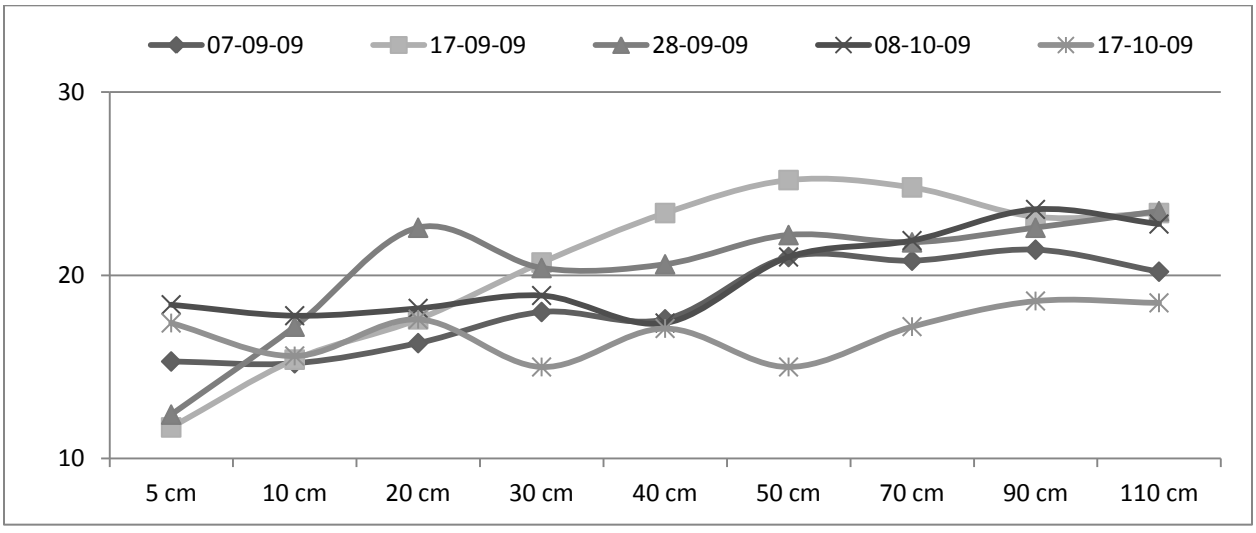

Figure 2-23: Soil moisture during Sep-Oct 2009

During the crop season 2010, from the observed soil moisture data, Figure 2-24 to Figure 2-28 depicts that soil moisture remained satisfactory during crop life from early growing stages to final maturity due to satisfactory rainfall and satisfactory temperature regime at crucial

stages of the crop. Throughout the crop life soil moisture remained more satisfactory in intermediate or major root zone and deep layers, whereas, it remained slightly deficit in shallow layers due to sensible heating of direct solar radiation. Overall condition of soil moisture was satisfactory due to satisfactory availability of irrigated/rain water during crucial stages.

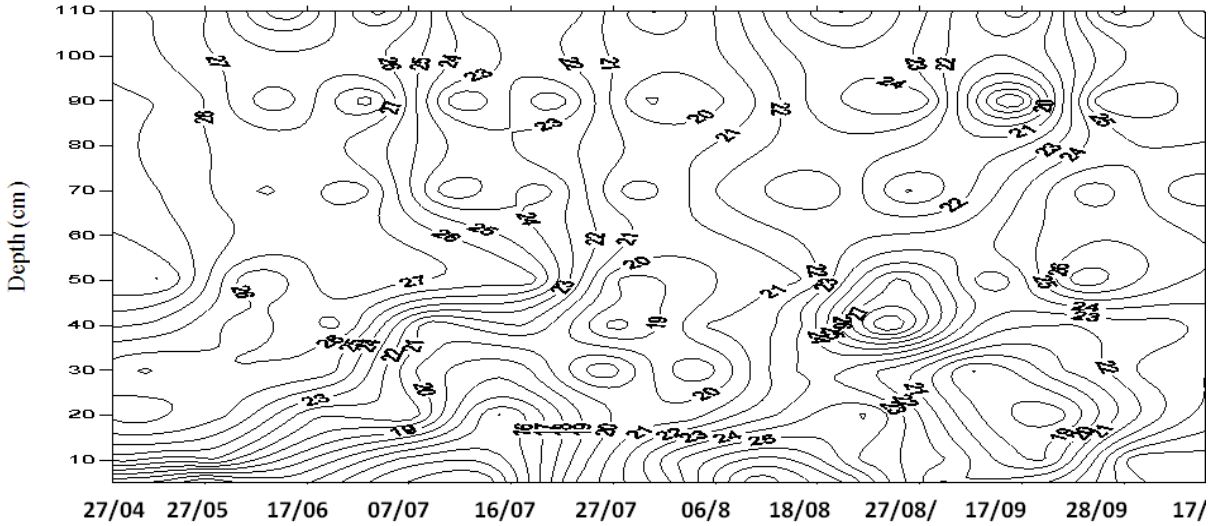

Figure 2-24: Soil moisture chrono Isopleths for Kharif Crop at Tandojam for the year 2010

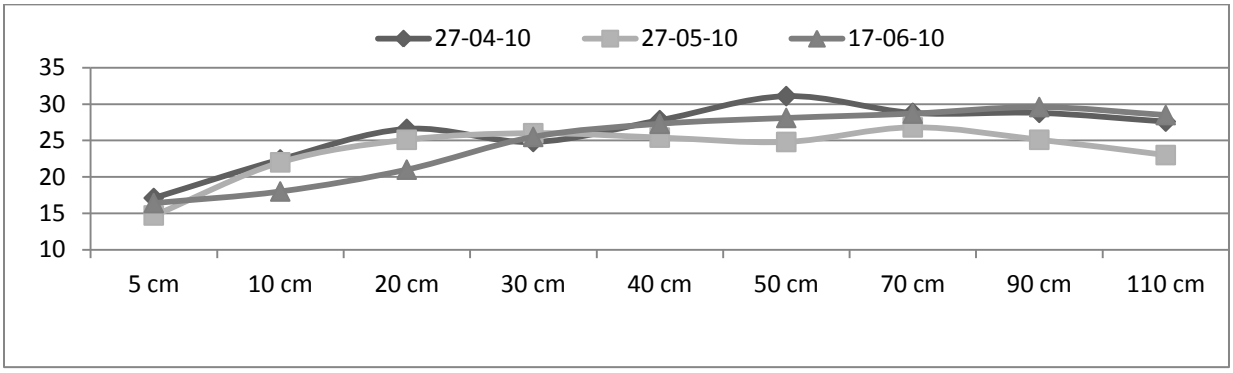

Figure 2-25: Soil moisture during April to June 2010

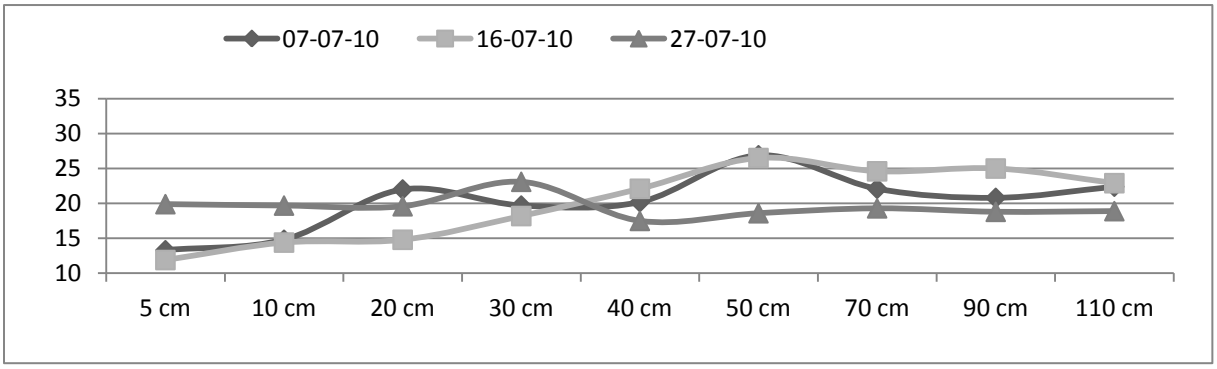

Figure 2-26: Soil moisture during Jul 2010

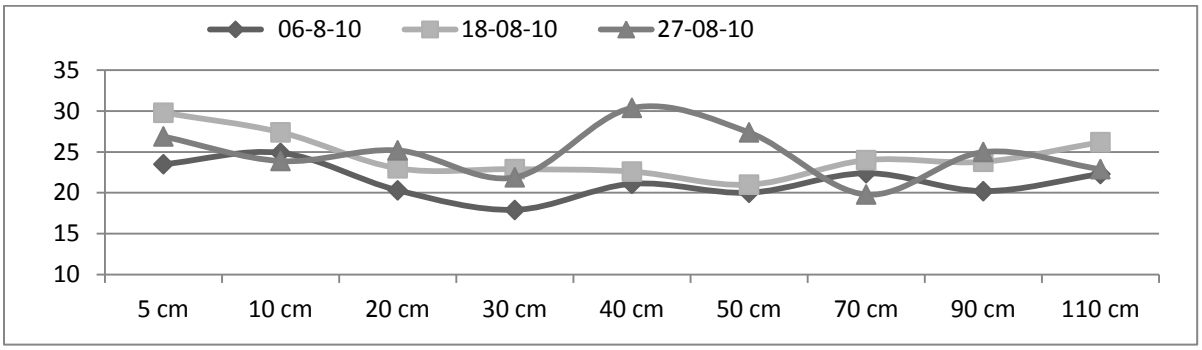

Figure 2-27: Soil moisture during August 2010

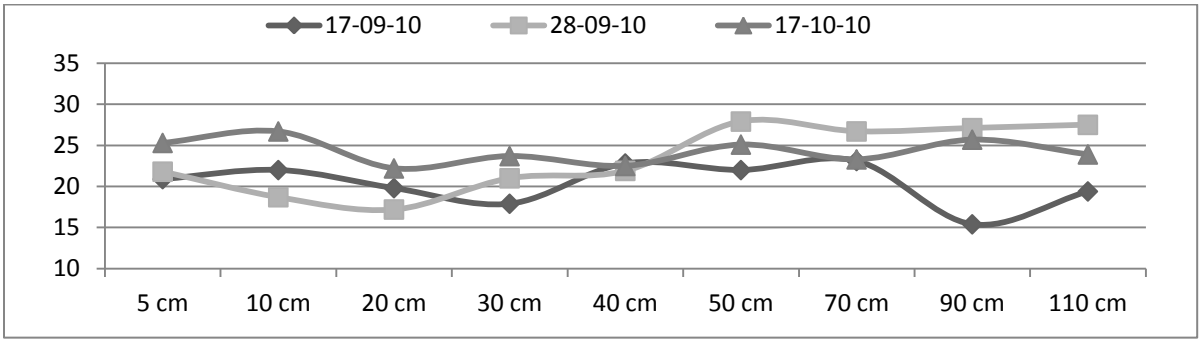

Figure 2-28: Soil moisture during Sep-Oct 2010

During the crop season 2011, from the observed soil moisture data, Figure 2-29 to Figure 2-32 depicts that soil moisture remained mostly satisfactory during the crop life. Soil moisture remained more satisfactory in intermediate or major root zone and deep layers, whereas, it remained slightly deficit in shallow layers due to sensible heating of direct solar radiation. Overall condition of soil moisture was satisfactory due to satisfactory availability of irrigated water during crucial stages.

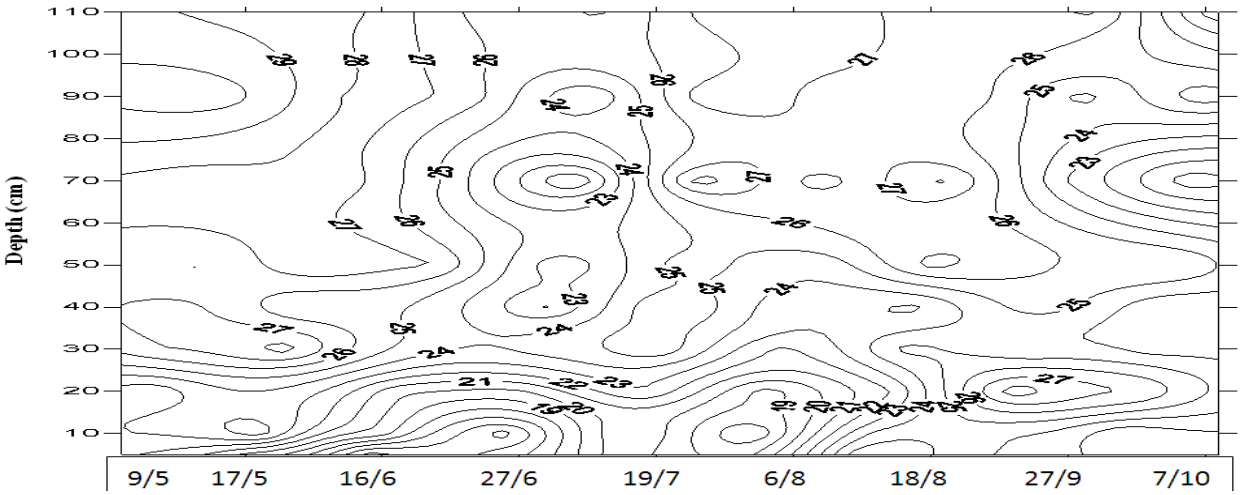

Figure 2-29: Soil moisture chrono Isopleths for Kharif Crop at Tandojam for the year 2011

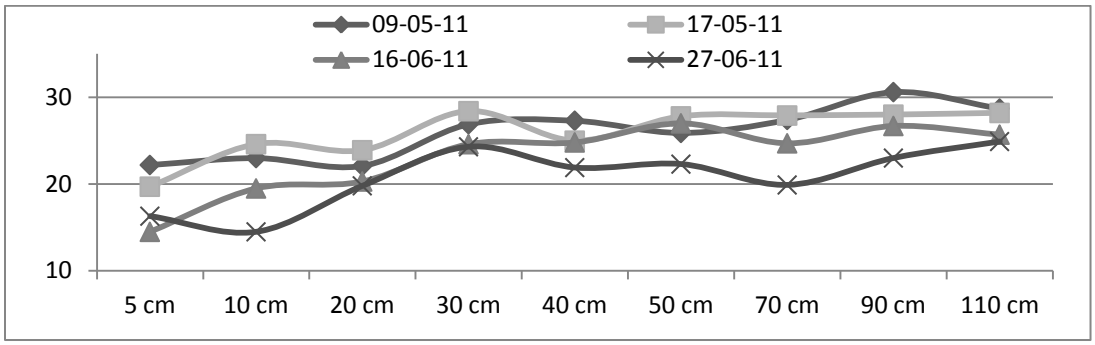

Figure 2-30: Soil moisture during May to June 2011

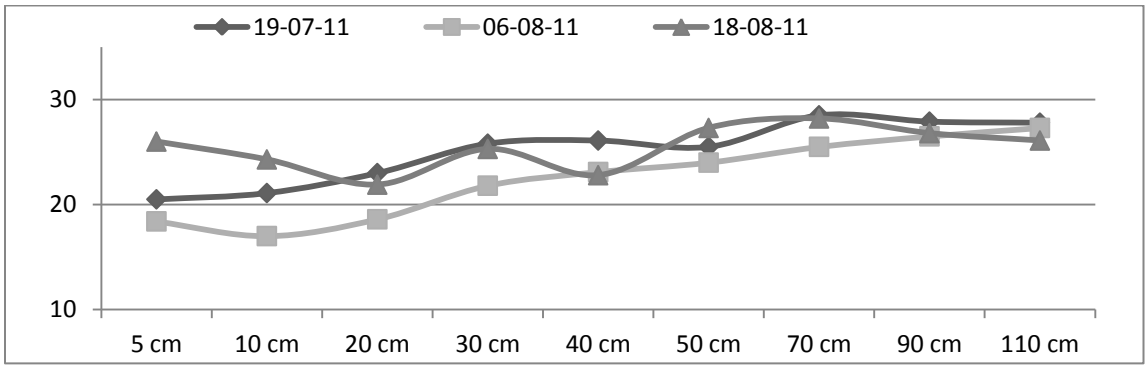

Figure 2-31: Soil moisture during Jul-Aug 2011

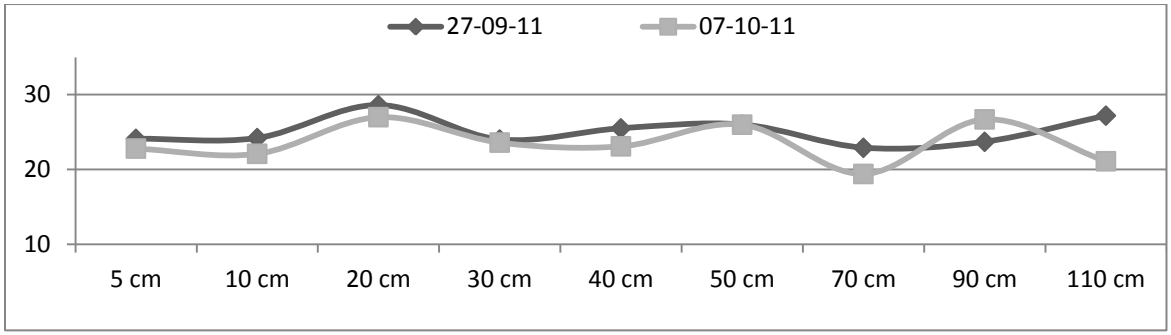

Figure 2-32: Soil moisture during Sep-Oct 2011

2.2.5. Soil Temperature and Crop Growth

Soil temperature plays promising role in crop growing period, right from the germination to maturity. In comparison to air temperature, the amplitude of variation in soil temperature is much more pronounced because of the varying characteristics and composition of soil. Soil temperature influences the germination of seeds, the functional activity of the root system, the incidence of plant diseases and the rate of plant growth [10].

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 °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 RAMC Tandojam situated near the experimental field of cotton 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.

During the crop season 2007, soil temperature was observed above normal at all depths. The rise was minimum in the month of August during boll-opening/early maturity stages due to monsoon rains.

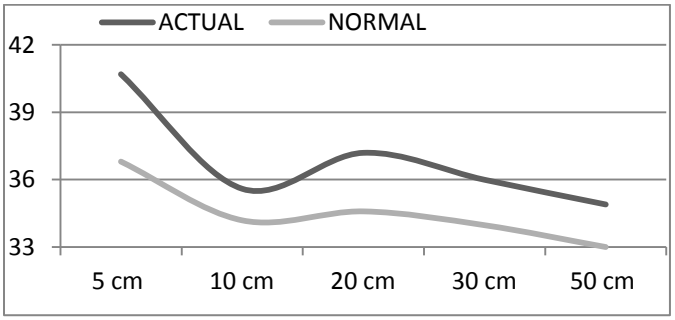

Figure 2-33: Soil temperature during May-2007

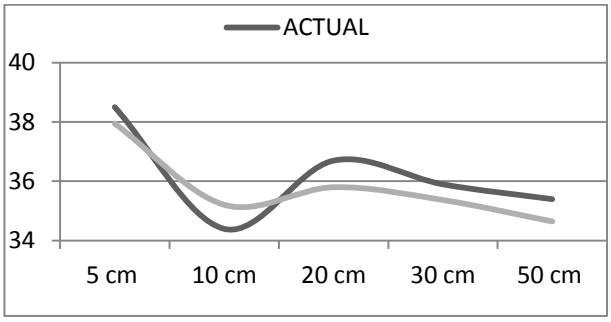

Figure 2-34: Soil temperature during June-2007

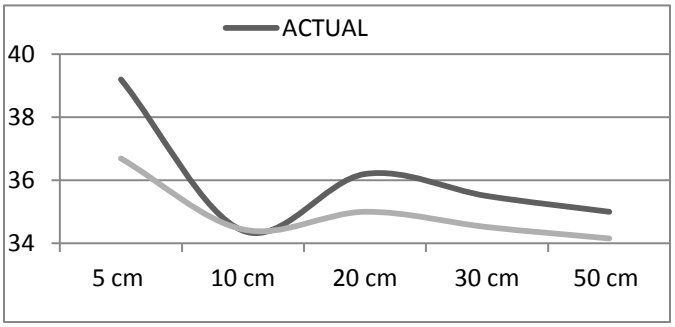

Figure2- 35: Soil temperature during July-2007

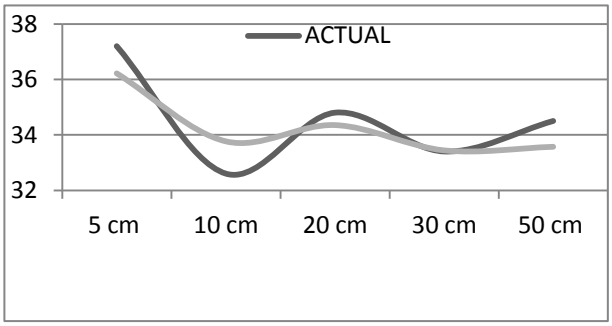

Figure 2-36: Soil temperature during August-2007

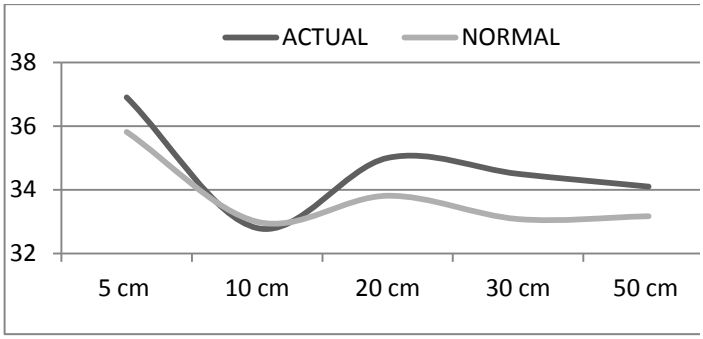

Figure 2-37:Soil temperature during September-2007

During the crop season of 2008, soil temperature was observed mostly normal to above normal at all depths. The rise in temperature was observed more significant at shallow layers than deep soils.

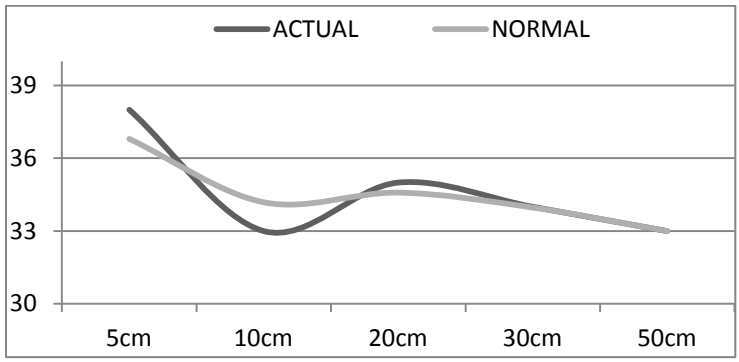

Figure 2-38: Soil temperature during May-2008

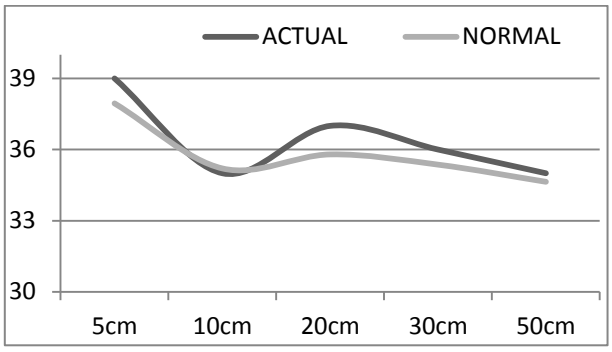

Figure 2-39: Soil temperature during June-2008

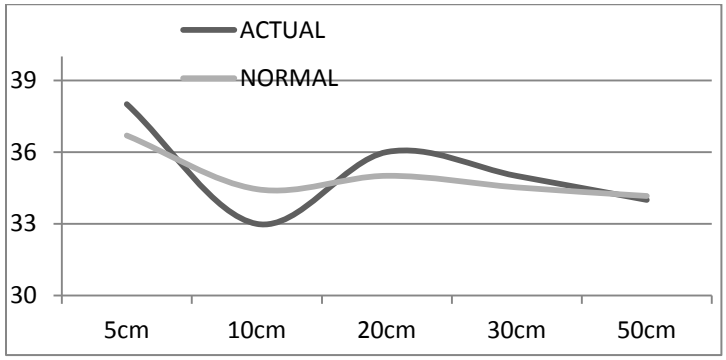

Figure 2- 40: Soil temperature during July-2008

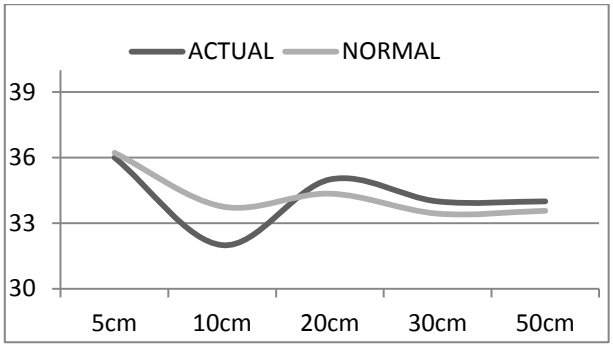

Figure 2-41: Soil temperature during August-2008

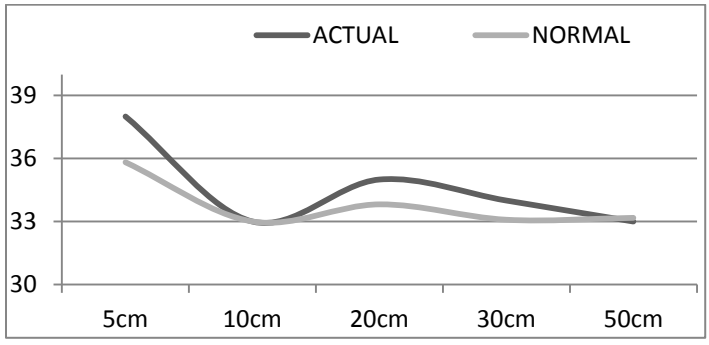

Figure 2-42:Soil temperature during September-2008

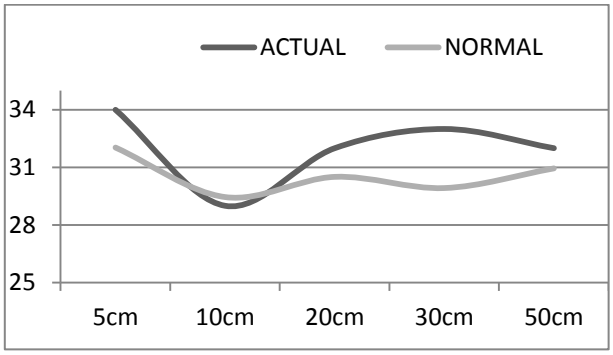

Figure 2-43: Soil temperature during October-2008

During the crop season 2009, soil temperature was observed mostly above normal up to boll opening stage and remained below normal at later maturity stage. The rise was observed more at shallow layers than deep layers.

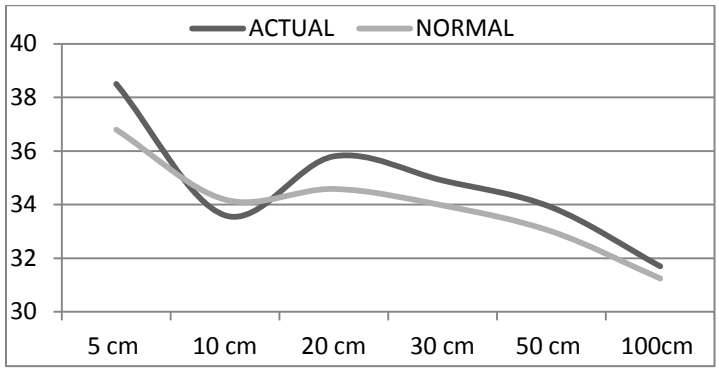

Figure 2-44: Soil temperature during May-2009

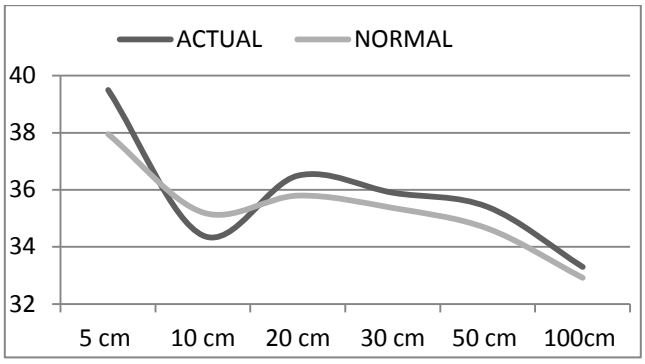

Figure 2-45: Soil temperature during June-2009

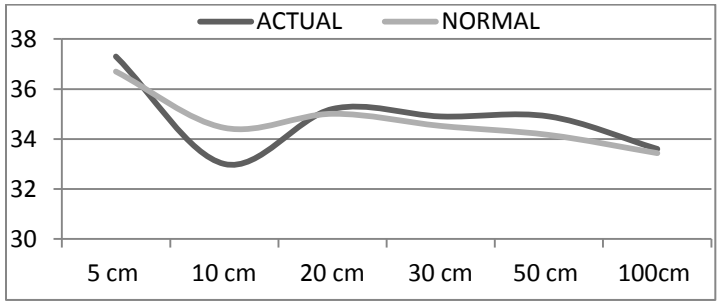

Figure 2-46: Soil temperature during July-2009

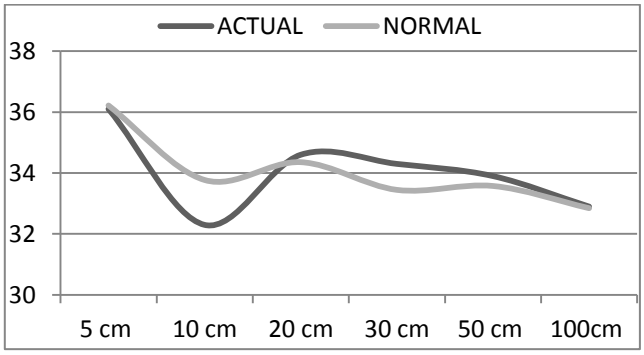

Figure 2-47: Soil temperature during August-2009

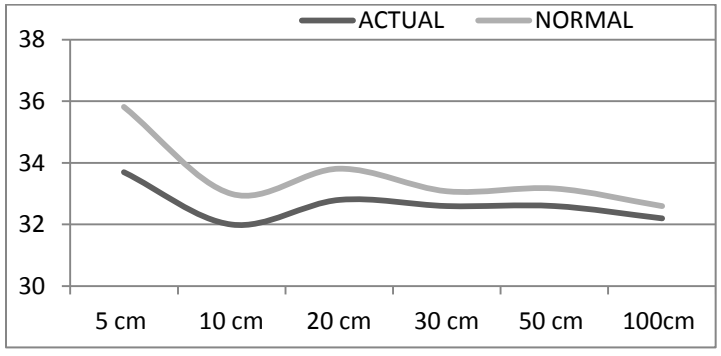

Figure 2-48:Soil temperature during September-2009

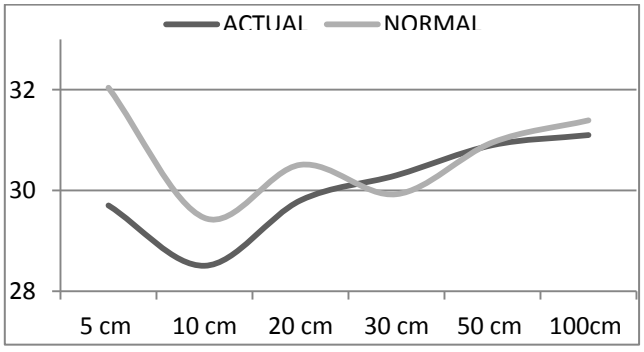

Figure 2-49: Soil temperature during October-2009

During the crop season 2010 in the month of April, soil temperature was observed mostly above normal at all depths. The rise was observed more at shallow layers than deep layers.

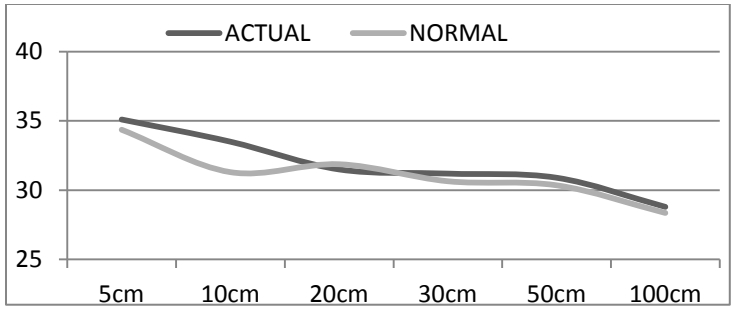

Figure 2-50: Soil temperature during April-2010

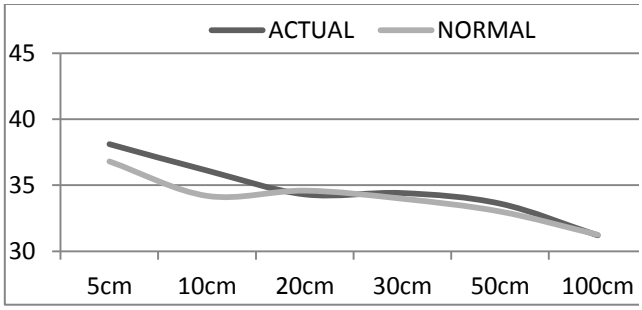

Figure 2-51: Soil temperature during May-2010

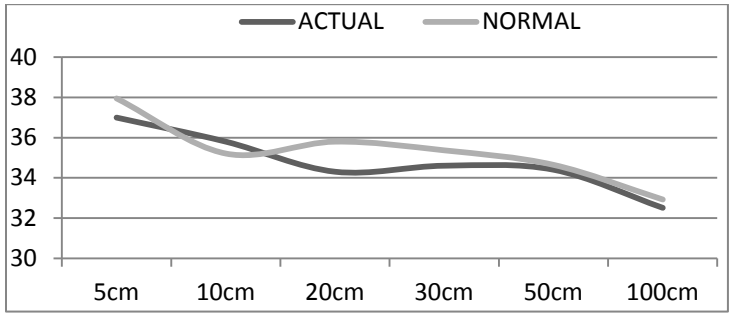

Figure 2-52: Soil temperature during June-2010

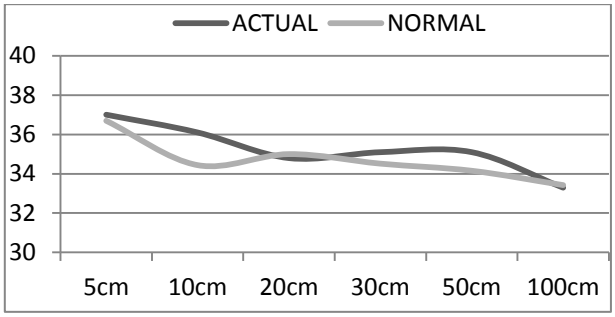

Figure 2-53: Soil temperature during July-2010

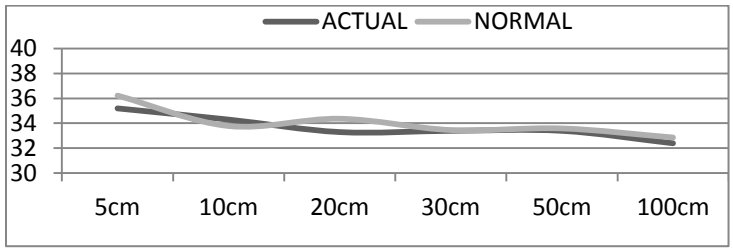

Figure 2-54:Soil temperature during August-2010

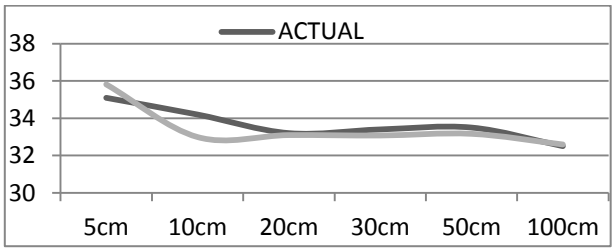

Figure 2-55:Soil temperature during September-2010

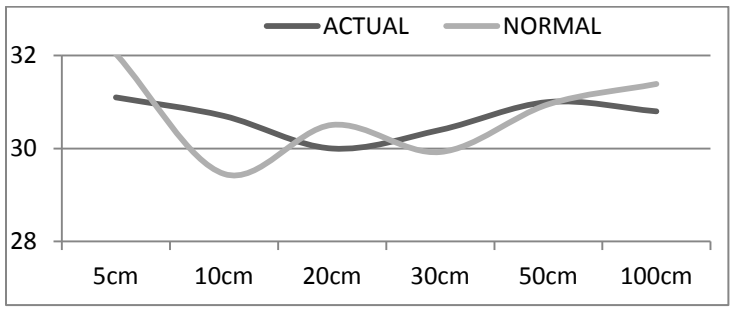

Figure 2-56: Soil temperature during October-2010

During the crop life of 2011, soil temperature was observed normal to below normal throughout crop life, which also indicates that soil moisture condition, remained satisfactory during crop life. It also concludes that crop growth was not suffered due to any abnormal rise in soil temperature at any stage.

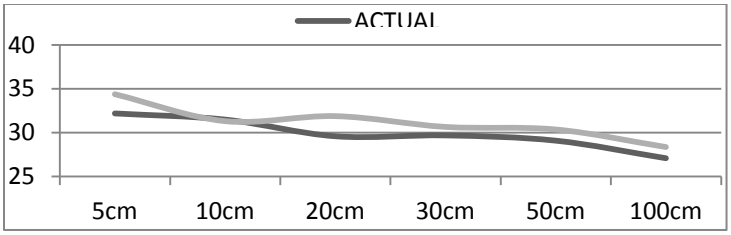

Figure 2-57: Soil temperature during April-2011

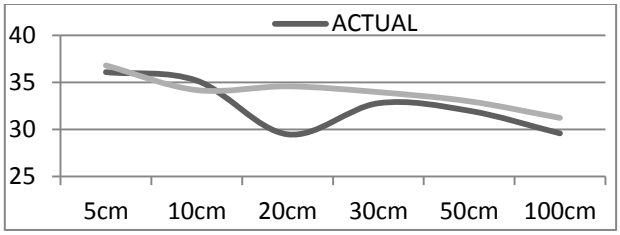

Figure 2-58: Soil temperature during May-2011

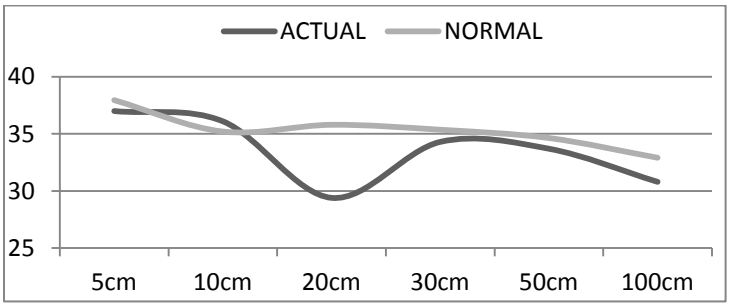

Figure 2-59: Soil temperature during June-2011

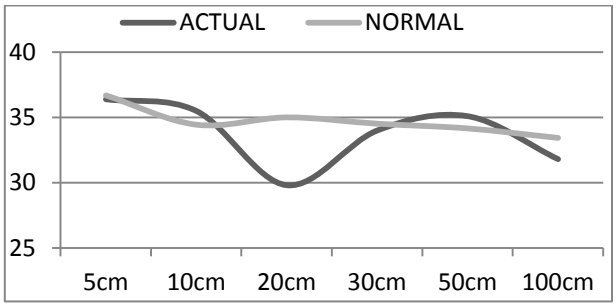

Figure 2-60: Soil temperature during July-2011

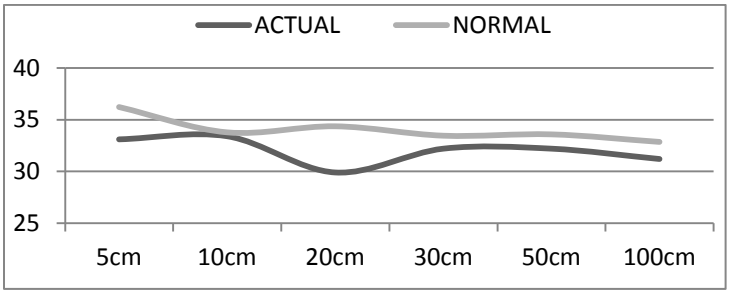

Figure 2-61:Soil temperature during August-2011

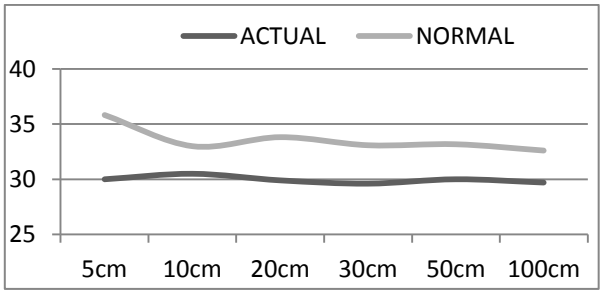

Figure 2-62:Soil temperature during September-2011

2.2.6. Heat Units or Growing Degree Days Consumption during Crop Growth

Heat units or Growing Degree Days are simple means of relating plant growth, development, and maturity to air temperature. Heat units are often used to estimate or predict the length of different phases of development in crop plants.

Heat units summation is related to crop development rather than growth because crop growth is related to dry matter formation through photosynthesis. It means that crop requires a particular amount of heat units to be matured/ harvested. If this amount is consumed by the crop, it will be ready for harvesting. But it is not necessary that crop growth may also be completed [10].

2.2.6.1. Methods of Calculation 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.

- **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

  $H.U = 0$:

  If T<Tb; where Tb is biological zero, which is the temperature below which growth stops. For cotton crop its value is 5°C. Crops go in dormancy when temperature drops below the biological zero.

- **Active Method:** This method incorporates the biological zero or base temperature of the crop,

  Heat units with effective method are calculated as under:

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

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

2.2.6.2. Heat Units Consumption During 2007

Interphase period for cotton crop during the crop season 2007 and corresponding heat units at Tandojam observed at different Phenological stages varies from phase to phase. Total heat units consumed by the crop were 4386 accumulated from Germination to Maturity in 143 days.

Table 2-1: Heat Units Accumulation for the Crop during 2007

S.No.	Inter Phase	Period	No. of Days Taken	Cumulative Total	Degree Days	Cumulative frequency
1.	Date of sowing	15-05-07	-	-	-	-
2	Germination	15-05-07 to 22-05-07	8	8	259	259
3	Emergence	23-05-2007 to 29-05-2007	7	15	222	481
4	Third true leaf	30-05-2007 to 27-06-2007	29	44	910	1391
5	Budding	29-06-2007 to 24-07-2007	27	71	825	2216
6	Flowering	28-07-2007 to 23-08-2007	27	98	833	3049
7	Boll opening	26-08-2007 to 25-09-2007	31	129	946	3995
8	Maturity	27-09-2007 to 10-10-2007	14	143	391	4386
9	Date of Harvesting	17-10-2007				

2.2.6.3. Heat Units Consumption During 2008

Interphase period for cotton crop during the crop season 2008 and corresponding heat units observed at different Phenological stages varies from phase to phase. Total heat units consumed by the crop were 4152 accumulated from Germination to Maturity in 135 days. Due to comparatively late sowing and significant rise in daily mean temperature in June during third leaf and budding stages, the crop consumed the required heat units up to maturity earlier. Cotton crop normally takes 140 to 145 days to be matured in lower Sindh.

Table 2-2: Heat Units Accumulation for the Crop during 2008

S.No	Inter Phase	Period	No. of Days Taken	Cumulative Total	Degree Days	Cumulative Frequency
1	Date of sowing	18-05-2008				
2	Germination	18-05- to 24-05	7	7	196	196
3	Emergence	25-05- to 30-05	6	13	199	395
4	Third True Leaf	31-05- to 24-06	25	38	810	1205
5	Budding	25-06- to 21-07	27	65	840	2045
6	Flowering	22-07- to 15-08	25	90	752	2797
7	Boll opening	16-08-2 to 14-09	30	120	876	3673
8	Maturity	15-09- to 30-09	15	135	479	4152
9	Date of Harvesting	30-10-2008				

2.2.6.4. Heat Units Consumption During 2009

Interphase period for cotton crop during the crop season 2009 and corresponding heat units at observed at different Phenological stages varies from phase to phase. Total heat units consumed by the crop were 4565 accumulated from Germination to Maturity in 145 days.

Table 2-3: Heat Units Accumulation for the Crop during 2009

Inter-phase	Period up to 75% occurrence	Inter-phase duration	Heat units
Germination	16-05-2009 to 20-05-2009	5	300
Emergence	21-05-2009 to 26-05-2009	6	202
Third True leaf	30-05-2009 to 28-06-2009	30	1008
Budding	1-07-2009 to 28-07-2009	28	884
Flowering	1-08-2009 to 26-08-2009	26	823
Boll Opening	28-08-2009 to 26-09-2009	31	934
Maturity	27-09-2009 to 11-10-2009	15	414
Total (Sowing to Maturity)	16-05-2009 to 11-10-2009	151	4642

2.2.6.5. Heat Units Consumption During 2010

Interphase period for cotton crop during the crop season 2010 and corresponding heat units observed at different Phenological stages varies from phase to phase. Total heat units consumed by the crop were 4826 accumulated from Germination to Maturity in 148 days.

Table 2-4: Heat Units Accumulation for the Crop during 2010

Inter-phase	Period up to 75% occurrence	Inter-phase duration	Heat units
Germination	17-04-2010 to 23-04-2010	7	229.7
Emergence	24-04-2010 to 29-04-2010	6	199.9
Third True leaf	30-04-2010 to 27-05-2010	28	970.6
Budding	28-05-2010 to 25-06-2010	29	955.1
Flowering	26-06-2010 to 22-07-2010	27	878.6
Boll Opening	23-07-2010 to 24-08-2010	33	1022.0
Maturity	25-08-2010 to 12-09-2010	19	570.5
Sowing to Maturity	17-4-10 to 12-9-10	149	4826.4

2.2.6.6. Heat Units Consumption During 2011

Interphase period for cotton crop during the crop season 2011 and corresponding heat units observed at different Phenological stages varies from phase to phase. Total heat units consumed by the crop were 4372 accumulated from Germination to Maturity in 146 days.

Table 2-5: Heat Units Accumulation for the Crop during 2011

S.No	Inter Phase	Period	No. of Days Taken	Cumulative Total	Degree Days	Cumulative frequency
1.	Date of sowing	20-04-2011				
2	Germination	22-04-2011 to 29-04-2011	8	8	244	244
3	Emergence	30-04-2011 to 08-05-2011	9	17	290	534
4	Third true leaf	09-05-2011 to 27-05-2011	19	36	567	1101
5	Budding	28-05-2011 to 26-06-2011	30	66	999	2100
6	Flowering	27-06-2011 to 14-07-2011	18	84	571	2671
7	Boll opening	15-07-2011 to 16-08-2011	33	121	1029	3700
8	Maturity	17-08-2011 to 08-09-2011	23	146	672	4372
9	Date of Harvesting	20-10-2011				

2.2.7. Relative humidity and Reference Crop Evapotranspiration, ETo (mm/day) during crop growth

During the crop season 2007, relative humidity remained above normal throughout the crop, with maximum values during monsoon season, whereas, ETo remained below normal during most of the growing period. Overall soil and air moisture content was favorable for crop growth.

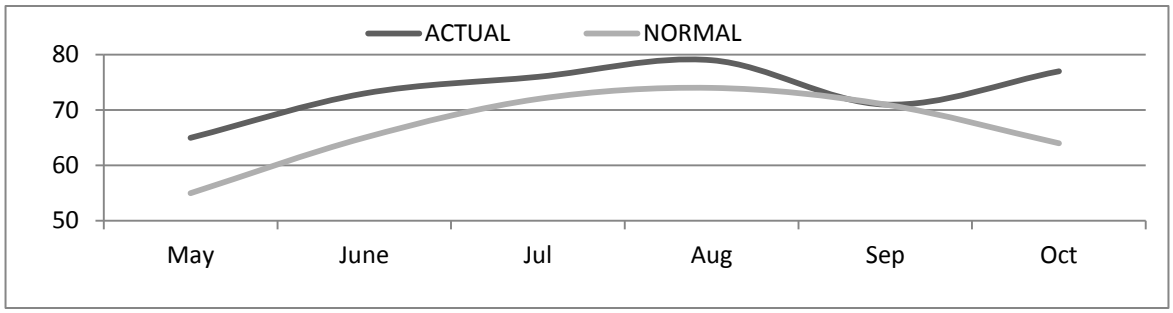

Figure 2-63: Mean RH during 2007

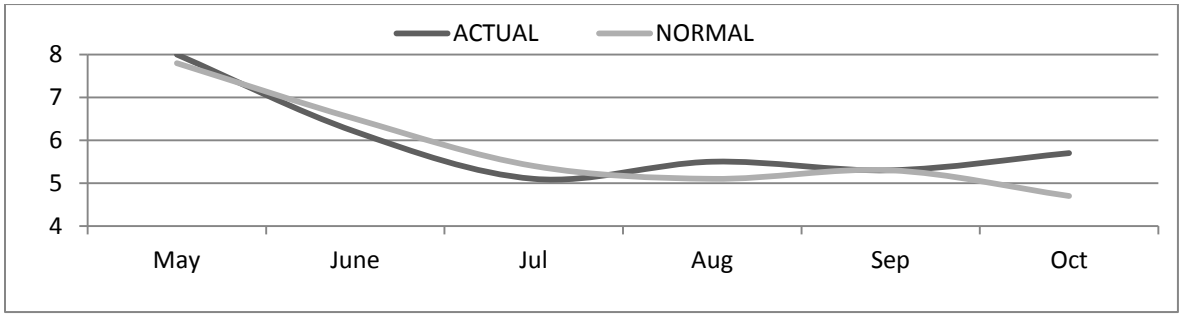

Figure 2-64: Mean ETo during 2007

During the crop season 2008, relative humidity remained above normal during most of the crop life except during later stages in September and October during which it remained below normal. Whereas, ETo remained below normal during most of the growing period. Overall soil and air moisture content was favorable for crop growth during crucial crop growing stages.

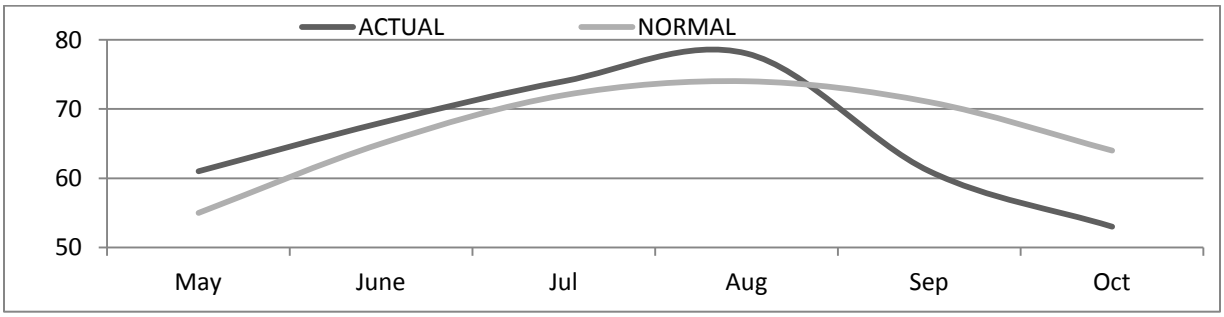

Figure 2-65: Mean RH during 2008

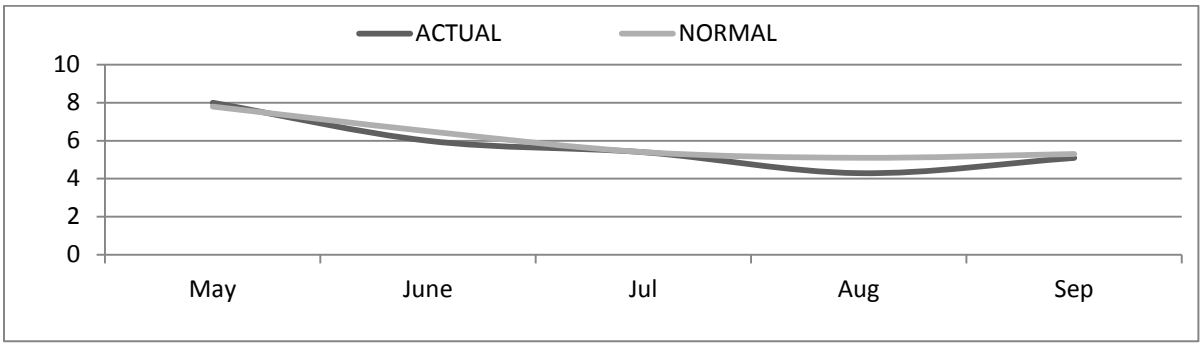

Figure 2-66: Mean ETo during 2008

During the crop season 2009, relative humidity remained above normal throughout the crop, with maximum values during monsoon season, whereas, ETo remained below normal during most of the growing period. Overall soil and air moisture content was favorable for crop growth.

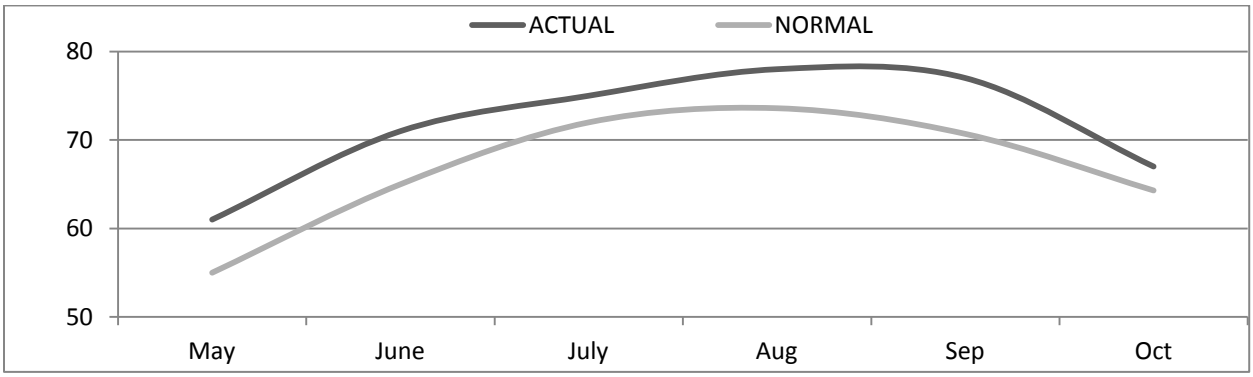

Figure 2-67: Mean RH during 2009

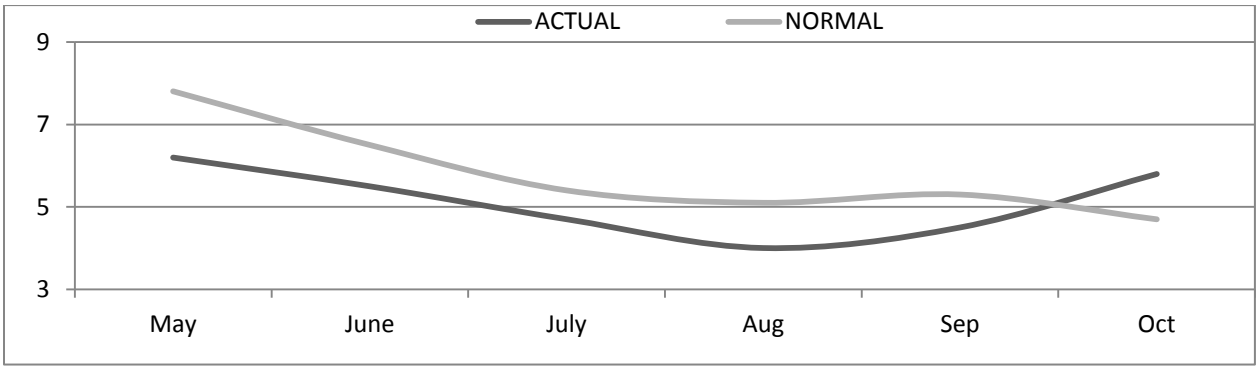

Figure 2-68: Mean ETo during 2009

During the crop season 2010, relative humidity remained above normal throughout the crop, with maximum values during monsoon season, whereas, ETo remained above normal during early growing stages and observed normal to below normal during later flowering and maturity stages of the crop. Overall soil and air moisture content was favorable for crop growth.

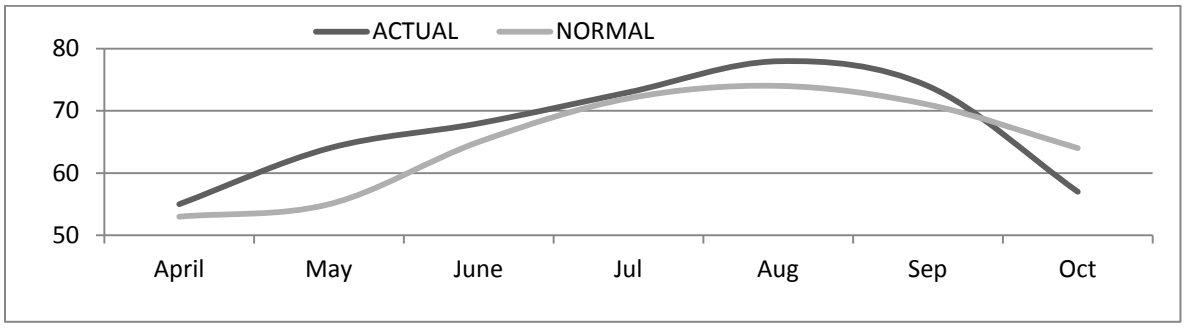

Figure 2-69: Mean RH during 2010

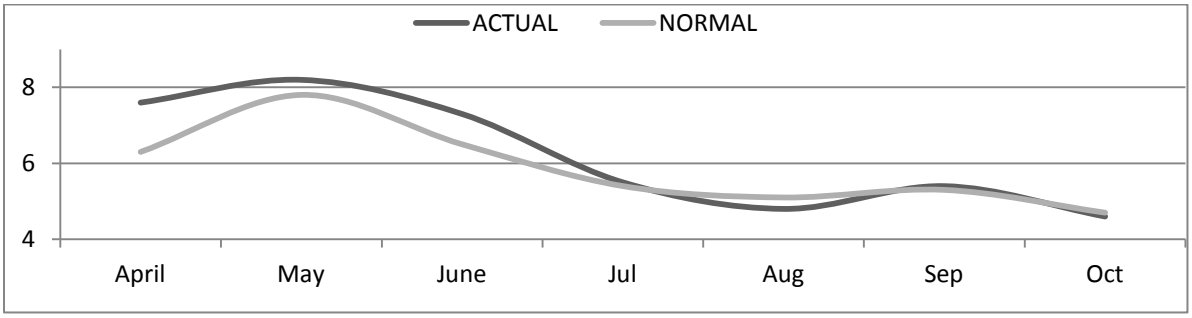

Figure 2-70: Mean ETo during 2010

During the crop season 2011, relative humidity remained normal to below normal during vegetative stages and remained above normal due to heavy rains/moist atmosphere in monsoon season during reproductive stages, whereas, ETo remained below normal during most of the growing period except during intermediate vegetative stages it remained slightly above normal. Overall soil and air moisture content was favorable for crop growth.

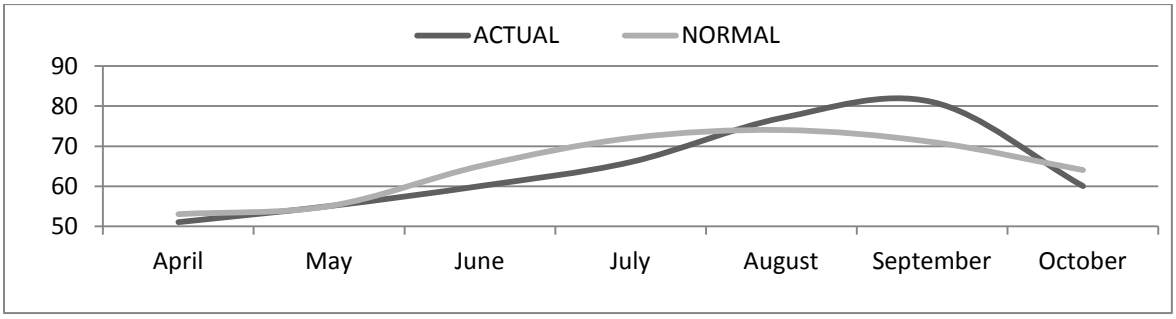

Figure 2-71: Mean RH during 2011

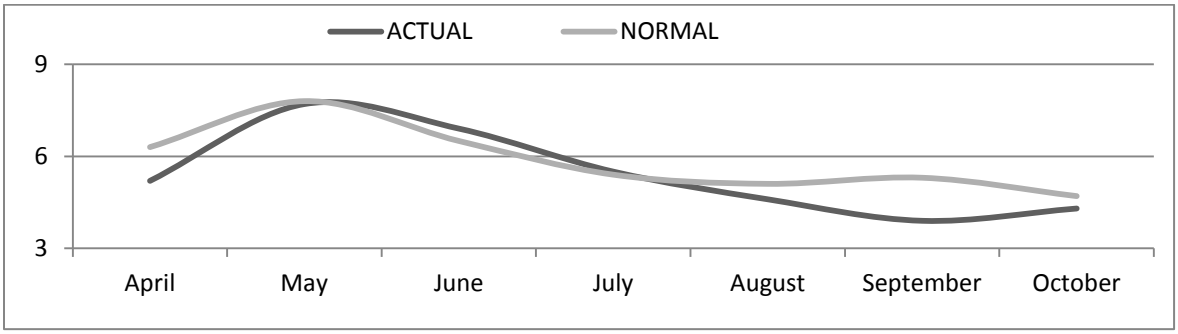

Figure 2-72: Mean ETo during 2011

2.2.8 **Crop Water Requirement (CWR) during the Crop Season 2007-2011**

The crop water requirement (ET crop) is defined as the depth (or amount) of water needed to meet the water loss through evapotranspiration. In other words, it is the amount of water needed by the various crops to grow optimally.

The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop, actively growing, completely shading the ground, free of diseases, and favorable soil conditions (including fertility and water). The crop thus reaches its full production potential under the given environment.

The crop water need mainly depends on:

- The climate: in a sunny and hot climate crops need more water per day than in a cloudy and cool climate.
- The crop type: crops like maize or sugarcane need more water than crops like millet or sorghum.
- The growth stage of the crop; fully grown crops need more water than crops that have just been planted.

Calculation of Crop Water Requirement (CWR)

After determining ETo, the ET crop/crop water requirement (CWR) can be predicted using the appropriate crop-coefficient (Kc)

ETcrop = Kc. ETo or CWR = Kc. ETo

Crop coefficient (Kc) is actually the ratio of maximum crop evapotranspiration to reference crop evapotranspiration. For Cotton, this ratio becomes greater than 1 during the reproductive cycle (heading to grain formation) otherwise it remains less than 1 bearing minimum values during the early age of the crop and at maturity. The crop water requirement was calculated for the period from emergence to maturity. The sowing of cotton starts from the month of May and picking of cotton starts with the end of the summer season and continue till the peak of winter. A schematic variation of the crop coefficient related to different crop development stages under normal conditions is given in figure 2-21[12].

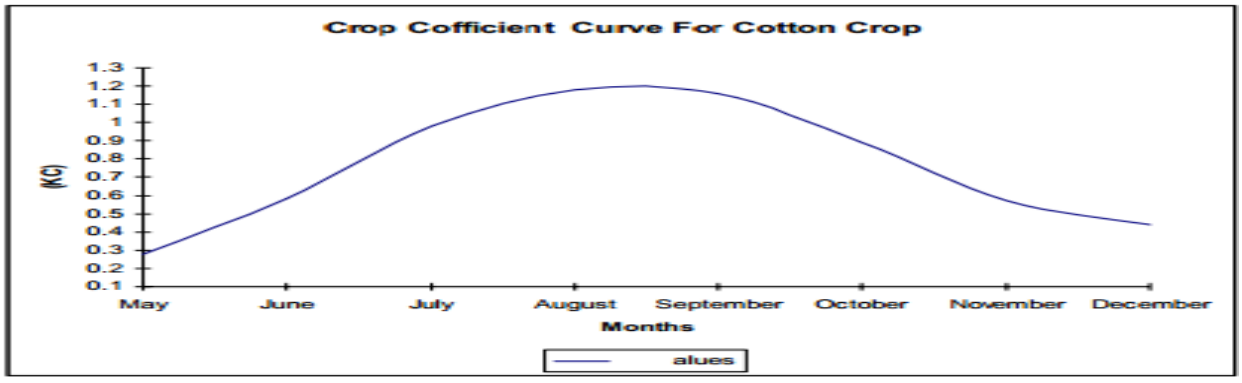

Figure 2-73: March of Crop Coefficient (Kc) for normal duration of Cotton growing season

During the Kharif Season 2007 in Tandojam, crop water requirement of cotton was observed normal to above normal at early growing stages and later stages of boll opening and maturity. Whereas it was observed normal to slightly below normal during intermediate stages (Fig 2-22 & Table 2-6). But total CWR was observed above normal of the crop.

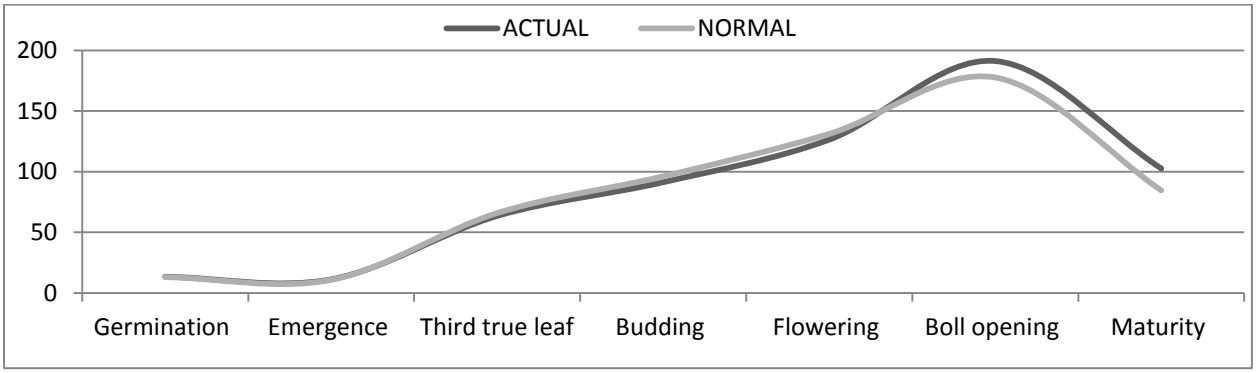

Figure 2-74: comparison of CWR with Normal values during the crop life 2007

Table: Crop water requirement during Kharif Season 2007 at Tandojam

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Germination	15-05-07 to 22-05-07	8	48	46.8	13.4	13.1
Emergence	23-05-2007 to 29-05-2007	7	40	39	11.2	10.9
Third True leaf	30-05-2007 to 27-06-2007	29	131.2	135.2	63.5	65.9
Budding	29-06-2007 to 24-07-2007	27	132.7	139.6	91.3	96.2
Flowering	28-07-2007 to 23-08-2007	27	128.7	134.1	126.4	131.2
Boll Opening	26-08-2007 to 25-09-2007	31	159.3	148.1	191.2	177.7
Maturity	27-09-2007 to 10-10-2007	14	85.5	70.5	102.6	84.6
Sowing to Maturity	15-05-2007 to 14-10-2007	143	**725.4**	**713.3**	**599.7**	**579.7**

During the Kharif Season 2008 in Tandojam, crop water requirement of cotton was observed normal to above normal during crop growth from early growing stages to maturity. Drop in CWR is observed at later stages from flowering to maturity (Fig 2-22 & Table 2-6). Thus the available irrigated and rain water mostly satisfied moisture requirement of the crop.

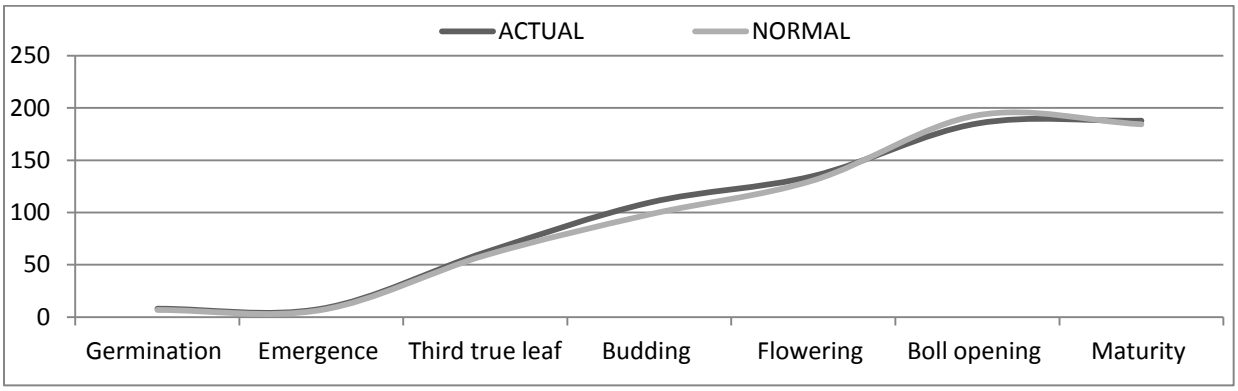

Figure 2-75: comparison of CWR with Normal values during the crop life 2008

Table: Crop water requirement during Kharif Season 2008 at Tandojam

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Germination	18-05- to 24-05	7	56	54.6	15.7	15.3
Emergence	25-05- to 31-05	7	56	54.6	16	15.6
Third True leaf	1-06- to 24-06	24	144	156	79.2	85.8
Budding	25-06- to 21-07	27	149.4	152.4	127.5	129.2
Flowering	22-07- to 15-08	25	118.5	130.5	128.7	143.1
Boll Opening	16-08-2 to 14-09	30	140.2	155.8	168.2	187.0
Maturity	15-09- to 30-09	15	76.5	79.5	91.8	95.4
Sowing to Maturity	18-5 to 30-09		**740.6**	**783.4**	**626.8**	**671.0**

During the Kharif Season 2009 in Tandojam, crop water requirement of cotton was observed normal to below normal during most of the crop growth (Fig 2-22 & Table 2-6). It means that crop growth did not suffer in any phase due to no sharp rise in crop water requirement. Thus the available irrigated and rain water fully satisfied moisture requirement of the crop, which resulted above normal crop growth and final yield.

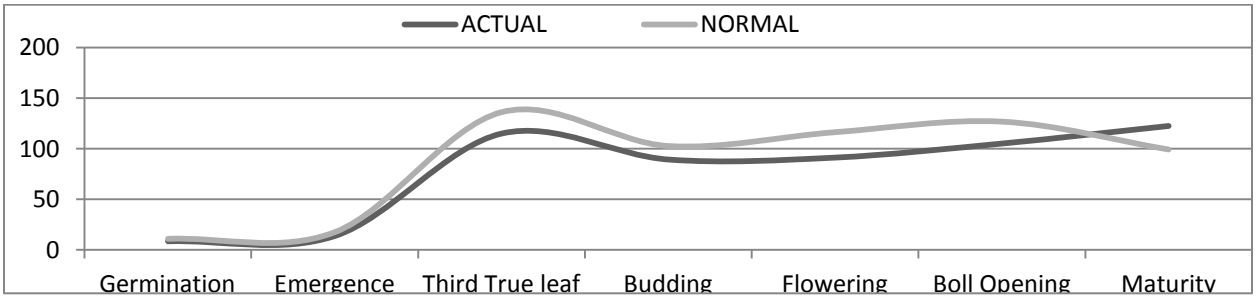

Figure 2-76: comparison of CWR with Normal values during the crop life 2009

Table 2-6: Crop Water Requirement (CWR) during Crop life 2009

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Germination	16-05-09 to 20-05-09	5	31	39	8.68	10.92
Emergence	21-05-09 to 28-05-09	8	49.6	62.4	13.88	17.472
Third True leaf	30-05-09 to 03-07-09	35	191.5	226.8	114.9	136.08
Budding	13-07-09 to 31-07-09	19	89.3	102.6	89.3	102.6
Flowering	05-08-09 to 23-08-09	19	76	96.9	91.2	116.28
Boll Opening	25-08-09 to 15-09-09	22	95.5	115.2	105.05	126.72
Maturity	18-09-09 to 08-10-09	21	121.8	98.7	122.38	99.17
Sowing to Maturity	16-05-09 to 8-10-09		654.7	741.6	545.39	609.242

During the Kharif Season 2010 in Tandojam, crop water requirement of cotton was observed normal to below normal during most of the crop growth (Fig 2-22 & Table 2-6). 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.

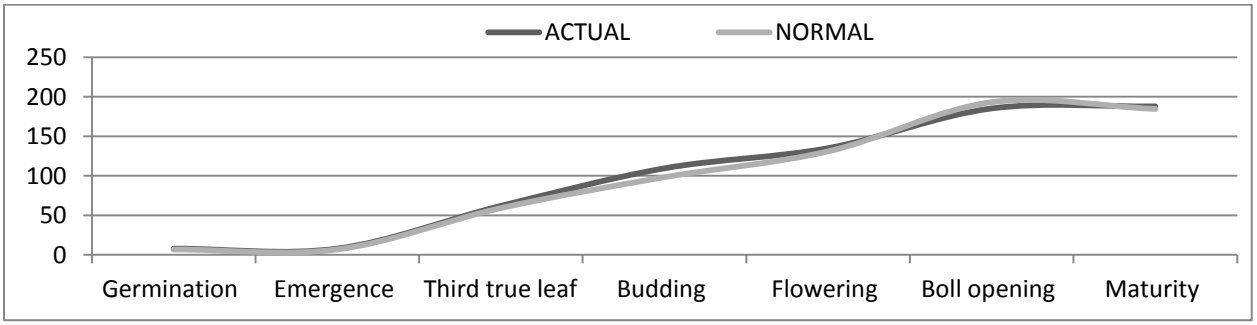

Figure 2-77: Comparison of CWR with Normal values during the crop life 2010

Table 2-7: Crop Water Requirement (CWR) During Crop Life

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Germination	17-04-2010 to 23-04-010	7	53.2	44.1	8.0	6.6
Emergence	24-04-2010 to 30-04-2010	7	53.2	44.1	8.0	6.6
Third True leaf	1-05-2010 to 27-05-2010	27	221.4	210.6	62.0	59.0
Budding	28-05-2010 to 25-06-2010	29	215.3	193.7	109.6	98.1
Flowering	26-06-2010 to 22-07-2010	27	157.5	151.3	135.0	130.7
Boll Opening	23-07-2010 to 24-08-2010	33	164.7	171	185.3	193.1
Maturity	25-08-2010 to 12-09-2010	18	97.2	95.4	187.9	184.4
Sowing to Maturity	17-4-2010 to 12-9-2010	149	**962.5**	**910.2**	**695.7**	**678.5**

During the Kharif Season 2011 in Tandojam, crop water requirement of cotton was observed normal to below normal during most of the crop growth (Fig 2-22 & Table 2-6). 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.

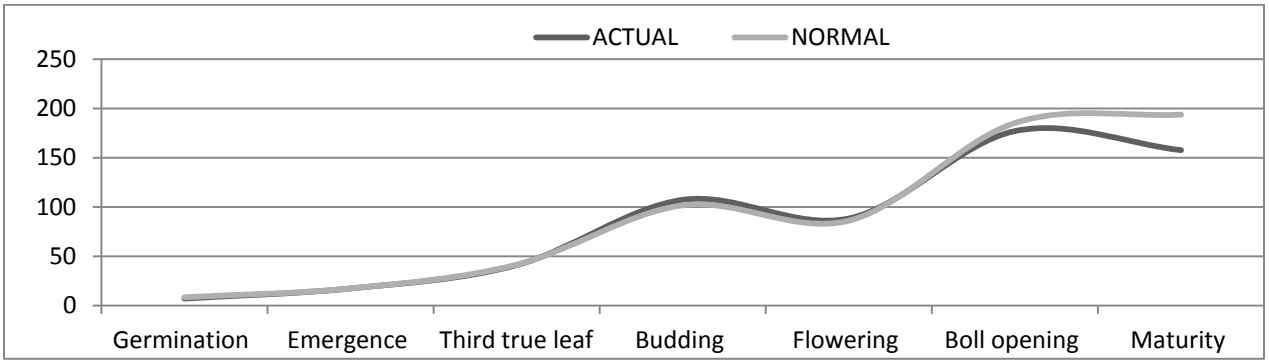

Figure 2-78: Comparison of CWR with Normal values during the crop life 2011

Table 2-8: Crop Water Requirement (CWR) During Crop Life

Inter-phase	period	Inter-phase duration	ETo (mm)	*ETo (mm)	CWR =Kc ETo (mm)	*CWR =Kc ETo (mm
Germination	22-04-2011 to 30-04-2011	9	46.8	56.7	7.0	8.5
Emergence	1-05-2011 to 08-05-2011	8	61.6	62.4	17.2	17.5
Third True leaf	09-05-2011 to 27-05-2011	19	146.3	148.2	41.0	41.5
Budding	28-05-2011 to 26-06-2011	30	210.2	200.2	107.3	101.7
Flowering	27-06-2011 to 14-07-2011	18	104.6	101.6	88.3	86.1
Boll Opening	15-07-2011 to 16-08-2011	33	167.1	173.4	177.1	185.1
Maturity	17-08-2011 to 08-09-2011	23	100.2	118.9	157.7	193.6
Sowing to Maturity			**836.8**	**861.4**	**595.7**	**634.0**

2.2.9 Wind and Crop Growth during 2007-2011

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 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 Kharif crop period 2007-2011, no wind storm 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.

2.3 Weather Parameters And their Impact on Crop Growth and Development at each Phenological Stage during Crop Period 2007-2011

2.3.1 Agrometeorological Summary of the Crop during each Phenological stage during the Crop Season 2007

Summary of crop cycle at each Phonological stage and weather at each phenological stage during the **crop season of 2007** are given below;

(i) Emergence

During this stage mean relative humidity was recorded 56% and mean air temperature was observed in range of 32.2-33.5°C. Soil temperature at sowing depth was around 40.7°C. number of plants emerged during the stage were reported comparatively slightly below normal due to moisture deficiency observed.

(ii) Third Leaf

Mean relative humidity during this phase was about 69%, mean air temperature ranged between 30.5°C and 34.0°C.Crop growth was reported almost normal. First irrigation was given to the field. But it did not fully satisfied crop water requirement.

(iii) Bud Formation

The mean air temperature ranged between 27.8°C and 35.5°C and mean relative humidity was around 75%. The growth at this stage was observed almost normal due to in time rainfall at very crucial time, 34.4 mm rain was reported in the last decade of June (from 23rd to 27th June).

(iv) Flowering

Mean air temperature during the phase ranged 29.80C – 32.7°C and relative humidity was 79%. Soil temperature was 39.2°C – 34.4°C. Satisfactory rains were reported at this stage, which along with one irrigation fulfilled crop water requirement. Minor damage was however reported to the crop due to last spell of rain amounting 44mm for 2 days. But almost normal growth was reported during the phase.

(v) Boll opening

The stage was accomplished (up to 75% occurrence) up to 10-08-2007. The mean air temperature was ranged between 28°C- 31.5°C and mean relative humidity was 78%. Satisfactory growth was reported during the stage.

2.3.2 Agrometeorological Summary of the Crop during each Phenological stage during the Crop Season 2008

Summary of crop cycle at each Phonological stage and weather response at each phenological stage during the **crop season of 2008** are given below;

i. Emergence

Mean relative humidity was 59% at the time of emergence. Mean air temperature during emergence ranged between 33 and 34°C. Soil temperature at sowing depth was around 38°C.

ii. Third Leaf

The mean relative humidity during this phase was about 68%; mean air temperature ranged between 30°C and 34°C. It took almost a month to reach the completion of third true leaf phase. The crop growth therefore was affected due to soil moisture deficiency observed at this stage, which is mainly due to above normal for 4°C rise in daily mean temperature. But later on the

crop started growing faster due to favorable weather conditions and completed its vegetative cycle to enter in the reproductive stages of development.

iii. Bud Formation

This is the first phase of reproductive cycle and this is sometimes confusing to differentiate between a vegetative bud and a flower bud. Here, we are concerned with the flower bud. The mean air temperature ranged between 30°C and 33°C.and mean relative humidity was around 74%. The growth at this stage was normal.

iv. Flowering

Flower buds open to flowers and hardly take a day to be open flower. This stage was mainly accomplished (up to 75% occurrence) up to end of July 2008 as table-1 exhibited. Mean air temperature during the phase ranged 27°C–32°C .and relative humidity was 79%. Soil temperature was 32°C– 38°C. In a couple of days, flowers gave rise to bolls at their bottom.

v. Boll Opening

The stage was accomplished (up to 75% occurrence) up to 18-08-2008. The mean air temperature ranged between 28°C-31°C and mean relative humidity was 78%. During this period total 42.8 mm rain was recorded, which positively supported crop growth and production.

2.3.3 Agrometeorological Summary of the Crop during each Phenological stage during the Crop Season 2009

Summary of crop cycle at each Phonological stage and weather at each phenological stage during the crop season of 2009 are given below;

(i) Emergence

The mean relative humidity was 66% at the time of emergence. Mean air temperature during emergence was found to be 33.0-34.0°C. Soil temperature at sowing depth was around 38.5°C.

(ii) Third Leaf

Mean relative humidity during this phase was about 71%; mean air temperature ranged between 30.0°C and 34.4°C.

(iii) Bud Formation

Mean air temperature ranged between 30.0°C and 34.5°C and mean relative humidity was around 77%. The growth at this stage was observed normal.

(iv) Flowering

Mean air temperature during the phase ranged 29.8°C – 30.8°Cand relative humidity was 79%. Soil temperature was ranged 36.1°C –32.3°C. Normal crop growth was observed during the stage.

(v) Boll Opening

The stage was accomplished (up to 75% occurrence) up to 25-08-2009. The mean air temperature was ranged between 27.2°C- 32.2°C and mean relative humidity was 77%. Rainfall amounting 72mm for a single day in this stage on 31st of August slightly affected/damaged the crop. Over all the crop growth at this stage reported satisfactory.

2.3.4 Agrometeorological Summary of the Crop during each Phenological stage during the Crop Season 2010

Summary of crop cycle at each Phonological stage and weather response at each phenological stage during the crop season of 2010 are given below;

(i) Emergence

The mean relative humidity was 58% at the time of emergence. Mean air temperature during emergence was found to be 31.5 - 33.5°C. Soil temperature at sowing depth was around 35.1°C.

(ii) Third Leaf

Mean relative humidity during this phase was about 63%, mean air temperature ranged between 32.5°C and 36.8°C. This phase ended up 02-06-2010.

(iii) Bud Formation

Mean air temperature ranged between 28.3.0°C and 35.0°C and mean relative humidity was around 69%. The growth at this stage was normal. Rainfall amounting 80mm was reported during first decade of June for 2 days, which positively affected crop growth and development during this stage.

(iv) Flowering

Mean air temperature during the phase ranged 30.5°C – 33.7°Cand relative humidity was 73%. Soil temperature was 37.0°C – 36.1°C. Rainfall amounting 28mm for 2 days was reported during this phase, which brought positive impact on crop growth during the decade. But weeds were reported in abundance.

(v) Boll Opening

The stage was accomplished (up to 75% occurrence) up to the end of August. The mean air temperature was ranged between 29.3°C- 32.3°C and mean relative humidity was 81%. Rains reported during the end of July (10mm for 3 days) and during the first half of August (95.4mm for 4 days). But sharp growth in size of the plant and excess of weeds were also observed during the stage.

2.3.5 Agrometeorological Summary of the Crop during each Phenological stage during the Crop Season 2011

Summary of crop cycle at each Phonological stage and weather response at each phenological stage during the crop season of 2011 are given below;

(i) Emergence

When plant emergence stage was completed, the field was divided into four replications. The mean relative humidity was 52% at the time of emergence. Mean air temperature during emergence was found to be 31.0 - 33.7°C. Soil temperature at sowing depth was around 35.1°C.

(ii) Third leaf

Mean relative humidity during this phase was about 57%, mean air temperature ranged between 32.2°C and 35.0°C.

(iii) Bud formation

The mean air temperature ranged between 32°C and 36.2°C and mean relative humidity was around 59%. The growth at this stage was normal.

(iv) Flowering

This stage started from 30-06-2011and ended on 18-07-2011 as table-1 exhibit. Mean air temperature during the phase ranged 30.3°C – 34.0°C and relative humidity was 66%.

(v) Boll opening

Mean air temperature was ranged between 27.5°C- 33.3°C and mean relative humidity was 74%. Total rainfall during this stage was reported 140.6mm for 3 days in August. This heavy rain/stagnant water badly affected/damaged the crop at this very sensitive stage.

(vi) Maturity stage

Mean air temperature ranged 25.5-31°C. Mean relative humidity was 87%. More than 250mm rain was reported for 14 days continuously during this phase, which further damaged/negatively affected the crop growth. This rain spell which started in the end of August on 28th of August and continued up to the mid of September (14 September) for 18 days destroyed/damaged the crop, which resulted poor crop production during 2011.

Chapter 3

3. Results and Discussion

Crop variety Sindh-1 and Niab-83 are recommended varieties of cotton in lower Sindh including Tandojam. Sindh-1 was cultivated for four years and Niab-78 was planted for one year in 2009 during the five years period 2007 to 2011.

Table 3-1: Brief Summary of Cotton crop cultivated during the period 2007-2011

Crop Season	Date of sowing and harvesting	Heat units/ Total days (sowing to maturity)	Quantity of seed per acre(kg)	Fertilizer added per acre	No. of irrigations	yield per hectare (kg)	Normal to potential yield per hectare (kg)	Crop Status
Sindh-1 2007	15-05-2007 to 17-10-2007	4386/143	14	1 bag DAP+2 Urea	4	1380	1400/2000	normal
Sindh-1 2008	18-05-2008 to 30-10-2008	4152/135	18	1 bag DAP+2 Urea	5	1400	1400/2000	Normal
Niab-78 2009	12-05-2009 to 21-10-2009	4642/151	14	1 bag DAP+2 Urea	4	1500	1500/1700	Normal
Sindh-1 2010	17-04-2010 to 12-10-2010	4826/149	14	1 bag DAP+2.5 Urea	3	1500	1400/2000	Above Normal
Sindh-1 2011	20-4-2011 to 20-10-2011	4372/140	14	1.5 bag DAP+2.5 Urea	3	1200	1400/2000	Below normal

According to Table-2.1 and Chapter-2 (Materials and Method), **the crop during 2007** was cultivated in time (10 May). Amount of seed cultivated per acre was sufficient for the crop. Fertilizer intake was also enough i.e. 1 bag DAP at the time of sowing and 2 bags Urea was added to the crop as split doze. Rainfall reported during the crop growth and available irrigated water did not fulfill crop water requirement at early growing stages from germination to third leaf. However 34.4mm rain for 4 days during budding stage in June decreased moisture deficiency to some extent. Deficiency of soil moisture was observed at early growing stages. But due to satisfactory rains along with irrigated water at later reproductive stages. Therefore available moisture condition favored normal crop growth. Mean daily temperature remained normal to below normal during crop life and day time temperatures observed above normal during early growing stages from planting to flowering stage and normal to below normal during

most of the reproductive stages. Crop water requirement of cotton was observed mostly normal from early growing to flowering stage. Whereas it slightly raised above normal at later boll opening and maturity stages (Fig 2-22 & Table 2-6). Total heat units consumed by the crop were 4565 accumulated from emergence to maturity stage in 145 days. 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 2007 recommended weedicides operations were performed in time, which also reinforced crop's growth and production. No pest or viral attack was observed on the crop during its life cycle. Optimum values/amount of meteorological and non-meteorological factors combined to normal crop growth and development. Rainfall amounting 72mm for 5 to 6 days slightly affected the crop growth at this important stage, which resulted some loss in final yield. However inspite of this minor loss overall crop growth, production and final yield was almost normal and no significant damage/loss was reported.

The crop during 2008 was cultivated almost in time (16 May). Amount of seed cultivated per acre was sufficient for the crop. Fertilizer intake was also enough i.e. 1 bag DAP at the time of sowing and 2 bags Urea was added to the crop as split doze. Rainfall reported during the crop growth and available irrigated water fulfilled crop water requirement at satisfactory level, which is also evident from soil moisture observations during crop growth. Soil moisture remained satisfactory at major root zone during most of the crop life. However deficiency to some extent was also observed at later maturity stage in September. Rainfall especially in the month of July and August during monsoon positively supported the crop growth. Mean daily temperature and day time maximum remained mostly normal to below normal during crop life. Therefore temperature regime mostly favored satisfactory crop growth and no abnormal rise of fall was observed during crop life. Soil temperature observed slightly above normal during crop growth. Relative humidity was observed above normal during crop life and ETo remained below normal during most of the crop life, which kept crop water requirement in control. Total heat units consumed by the crop were 4515 accumulated from emergence to maturity stage in 135 days. This concludes that the crop consumed the required amount of heat units earlier. Normally this amount of heat units is consumed by the crop in about 145 days. This is mainly due to above normal temperature observed in the month of June by 4°C during third leaf and budding stages.During 2008 recommended weedicides operations were performed in time, which also reinforced crop's growth and production. Pest attack of Jassides and Aphides were observed during monsoon, which negatively affected crop growth and development and also reduced final yield.

According to Table-2.1 and Chapter-2 (Materials and Method), **the crop during 2009** was cultivated in time (16 May). Amount of seed cultivated per acre was sufficient for the crop. Fertilizer intake was also enough i.e. 1 bag DAP at the time of sowing and 2 bags Urea was added to the crop as split doze. Rainfall reported during the crop growth and available irrigated water did not fulfill crop water requirement completely, which is also evident from soil moisture observations during crop growth. Soil moisture remained satisfactory at major root zone. However deficiency to some extent was also observed at early growing stages, boll opening and later maturity stage. Rainfall especially in the month of August during boll opening phase for a single day damaged/affected the crop to some extent, which also reduced the yield obtained. Mean daily temperature remained normal to below normal during crop life and day time

temperatures observed above normal during early growing stages from planting to flowering stage and normal to below normal during most of the reproductive stages. Therefore temperature regime mostly favored satisfactory crop growth and no abnormal rise of fall was observed during crop life. Soil temperature also observed mostly normal to above normal during early growing stages up to flowering stage. Whereas it remained normal to below normal during boll opening and maturity stages. Relative humidity was observed above normal during crop life and ETo remained below normal during most of the crop life, which kept crop water requirement in control. Total heat units consumed by the crop were 4642 accumulated from emergence to maturity stage in 151 days. No pest or viral attack was observed on the crop during its life cycle.

The crop during 2010 was cultivated in time (mid of April). Amount of seed cultivated per acre was sufficient for the crop. Fertilizer intake was also enough i.e. 1 bag DAP at the time of sowing and 2 bags Urea was added to the crop as split doze. In time irrigated water and effective rainfall during hot months from June to September thoroughly supported crop growth and fulfilled crop water requirement completely, which is also evident from soil moisture observations during crop growth. Soil moisture remained satisfactory at major root zone. However deficiency to some extent was also observed at early growing stages due to dry weather reported. Air and soil temperature regime s also supported satisfactory crop growth throughout crop life from planting to flowering stage and final maturity stages. Therefore temperature regime mostly favored satisfactory crop growth and no abnormal rise of fall was observed during crop life. Relative humidity was observed above normal during crop life and ETo remained below normal during most of the crop life, which kept crop water requirement in control. Total heat units consumed by the crop were 4826 accumulated from emergence to maturity stage in 149 days. During the crop season due to available irrigation and above normal rainfall reported at each phenological stage reinforced weeds growth and over growth of cotton plant was also observed, which slightly prolonged crop period from sowing to maturity and reduced the yield to some extent. Recommended weedicides operations were performed in time, which controlled weeds growth.. No pest or viral attack was observed on the crop during its life cycle. Optimum values/amount of meteorological and non-meteorological factors combined to normal growth and development as well as final yield.

According to Table-2.1 and Chapter-2 (Materials and Method), **the crop during 2011** was cultivated almost in time (20^{th} April). Amount of seed cultivated per acre was sufficient for the crop. Fertilizer intake was also enough i.e. 1 bag DAP at the time of sowing and 2 bags Urea was added to the crop as split doze. Rainfall reported during the crop growth and available irrigated water fulfilled crop water requirement completely, which is also evident from soil moisture and soil temperature observations during crop growth. Soil moisture remained satisfactory at major root zone. However rainfall especially in the month of August and September during boll opening, maturity stages and during picking damaged the crop. Stagnant water also affected the crop during August and September. Temperature regime of soil and atmosphere observed mostly observed below normal throughout crop life and no sharp or abnormal variation was observed in soil and air mean and day time maximum temperature. Therefore temperature regime mostly favored satisfactory crop growth. Moisture content of the atmosphere represented by relative humidity was observed above normal during crop life and ETo remained mostly below normal during most of the crop life, which kept crop water requirement in control. Total heat units consumed by the crop were 4565 accumulated from emergence to maturity stage in 145 days. Optimum values/amount of meteorological and non-meteorological factors combined to satisfactory crop growth and development. However major negative impact on crop was observed in August and September due to excess of stagnant water

which destroyed/damaged the crop as a result of heavy rain spells during monsoon reported consistently from the end of August till the mid of September.

3.1. Conclusion

It is thus concluded that wheat crop growth, development and final yield during Kharif crop period 2007 to 2011 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, timing and amount of rainfall, in time and required amount of fertilizer doze, day time temperature, weeds removing operations, pre-sowing practices on field and so on. Irrigation water was added 3 to 5 times, which satisfied most of the crops water requirement along with rain water during monsoon season. But the crop cultivated during 2007 suffered moisture deficiency to some extent due to deficiency of soil moisture at early growing stages. Heavy rain spells damaged or negatively affected the crop growth and consequently final yield during 2007, 2009 and 2011. It is also interesting to note that consistent rains along with three irrigations during 2010 produced excess of weeds and above normal height of the plant, which also affected the yield obtained during 2010.Two of the five crops during 2010 and 2011 were planted earlier in April. But it did not produce any positive impact regarding crop water requirement or crop yield. Crop water requirement ranged 545mm to 696mm. maximum CWR was recorded 696mm in 2010, followed by 626mm in 2008, 599mm in 2007 and 596mm in 2011.Heat units or growing degree days consumed by the crops during the period 2007 to 2011 ranged from 3848 to 4826. On average the crops consumed 4353 heat units in 138 days. On average per day consumption by crops is about 32 heat units.

3.2. Recommendations and Suggestions

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

1 – Farmers generally plant cotton late due to late harvesting of Rabi crop which results in drastic low yields because the crop is exposed to heat stress at early stages leading to the formation of reduced boll size. Late-planted crop has lower germination, fewer flowers, smaller heads, shriveled boll and lower biomass than the timely planted crop. Any delay in planting would reduce yield drastically. To achieve good yield, cotton sowing should be carried out well in time. Keeping the results of this study, it is suggested that the most suitable time of sowing under existing climate and available water in lower Sindh is full month of May.

2 – Cotton plant water requirement is maximum during flowering and boll opening and maturity stages followed by vegetative stages. Therefore farmers and other decision makers should make possible the availability of irrigation water to cotton crop keeping this order in mind to get maximum crop yield.

3- Farmers should take in time precautionary measures against any pest/fungus/viral etc. attack on crop, especially hot/humid period of monsoon.

4 – The frequency of extreme weather events like heat waves, flash flooding, and heavy spells with stormy winds has increased globally including Pakistan in the last decade due to climate change. Pakistan has also been o facing water shortages and drought conditions for the last several years due to lesser rains and high temperatures due to global warming which resulted in hampering of cotton production. In order to minimize the negative effects of climate change and accompanied global warming, drought and heat tolerant varieties need to be evolved in addition to the judicial use of available irrigation water. Keeping in mind the available water resources, it is also indeed necessary to decide suitable verities to be cultivated in a particular region.

5 – Farmers may be advised to be in contact with local and 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 to get in time weather advices to deal in better way with any present or coming water stress condition and to be aware of any weather related pest attack, especially during monsoon season and to get best results of fertilizer and irrigated water used.

6 – Frequent rains/irrigation some time sharply increases plant growth and elongates plant height above normal and speeds up weeds growth. Due to which crop stages take more time for completion and number of flowers emerge on each plant decrease, which ultimately affect final yield and lengthens crop life span. As a result sowing of coming Rabi crop on the same field becomes late. Therefore farmers should carefully add irrigated water in rainy conditions.

7 – Weeds being the main robbers of plant food from soil; space and even light required for cotton plants, be controlled by cultural practices and in case of heavy infestation, may be eliminated by application of recommended herbicides and weedicides. This technique will definitely increase the yield.

8 – Seed of high yielding cotton varieties resistant to rusts, smuts, etc. approved by Agricultural Department for a particular region in a particular amount must be used. Seed should be treated with a suitable insecticide carefully before sowing.

9 – Timely application of nitrogen-phosphoric fertilizers should be done.

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

11 – Crop rotation is an important factor that enriches the fertility of the land, which should not be ignored.

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