Weather and Cotton Crop Development in Central Punjab (Faisalabad, 2015)

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Abstract

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 each phenological stage of cotton crop, cultivated in the field of Ayub Agriculture Research Institute Faisalabad (Central Punjab) during the Kharif Seasons 2015. Beside this some other factors e.g., time of sowing, fertilizer intake, insecticides, and weeds removing operations and supplied irrigated water have also been studied. The crop accumulated 3013 heat units in 140 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 depends upon mainly on the time of sowing, irrigation, in time use of chemicals against weeds and pest/viral attacks, variation in rainfall and heavy rain spells from flowering to maturity stages, day time rise in temperature and so on. This study is based upon the data collected at the field and meteorological observatory located at the Ayub Agriculture research Institute, Faisalabad. 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 Faisalabad and other cotton growing areas of central Punjab.

Chapter 1

INTRODUCTION

This study is based upon field observations of cotton crop at Regional Agrometeorological Center Faisalabad, cultivated in the experimental field of Plant Physiological section of AARI Faisalabad during the Kharif season 2015. The cotton crop variety FH-Lalazar was cultivated in the experimental field. 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 Central Punjab (Study Area)

Pakistan has a variable climate, ranging from arid (33-254mm annual rainfall) in the south to humid (1016-2032mm annual rainfall), sub-humid (508-1016mm annual rainfall) and semi-arid (254-508mm annual rainfall) in the north. The Indus River that originates from the north along with its tributaries irrigates the great plains of the country including Central Punjab. Chaudhry and Rasulfound that about 2/3 of the total agriculture area lies in the arid climate. [1]

The study has been conducted for "Faisalabad District" in Central Punjab with longitude 73.1^{o}E, latitude 31.43^{o}Nand elevation of 184.5m from mean sea level. The climate of central and southern Punjab possesses the dry semi-arid agro-climatic characteristics (Figure– 1.1) but well managed canal irrigation system has placed it among the highly productive agriculture zones. Mainly summer monsoon produces more rainfall and winter has a little contribution. Day time temperature reaches above 40°C during summer from April to September except some occasional relief from monsoon rains and decreases the evaporation demand of the atmosphere. The winter season starts from November and continues till March. December, January and February are the coldest months. In winter, night time temperature drops below 0°C[2]. More detail about the climate of Faisalabad during Kharif season is shown in the figures (1.2& 1.3). The highest amount of rainfall occurs during Kharif season in the month of July followed by September and August. Day time mean maximum and night time mean minimum temperature gradually decrease from November upto January and then increase gradually [3].

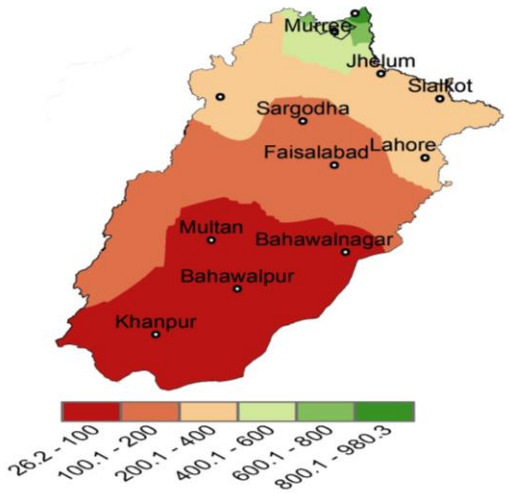

Figure 1.1:Mean Annual Rainfall (mm) of Punjab [Normal (1981-2010)]

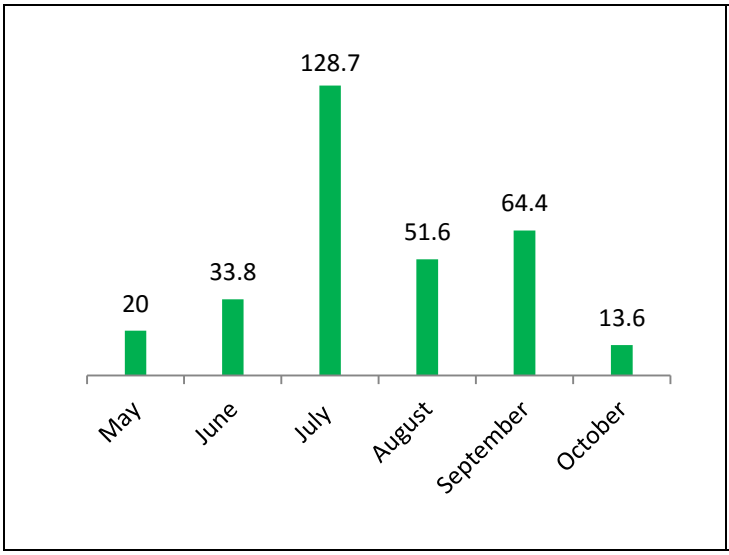

Figure 1.2: Monthly Mean Annual Rainfall (mm) of Faisalabad during Kharif Season

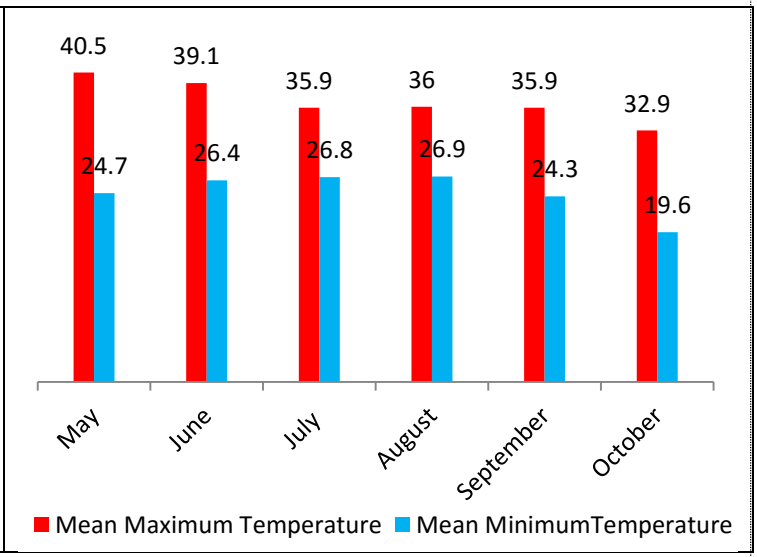

Figure 1.3: Mean daily Maximum and Minimum Temperature (ºC) of Faisalabad during Kharif Season

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 beside other important factors. Therefore year to year variation in the spatial and temporal distribution of precipitation causes changes in the amount of available water for irrigated agricultural regions, which consequently brings up and down in the annual cotton production. Sometime 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, which significantly affect crop growth and yield. Rain, just after sowing, causes decrease in the number of germinated cotton seeds. Heavy rains in particular, damage and cause shedding

of flowers/bolls from flowers to maturity stages. 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 along with variations in soil temperature and moisture is analyzed to understand crop growth and development throughout the crop life and their impact on final yield of the crop.

1.3 Objective of the Study

- To analyze and study the impact of various meteorological parameters on crop growth and development.
- To investigate the water satisfaction sensitivity of crop in Faisalabad region.
- To develop the relationship between weather parameters, crops life cycle and yield obtained.
- To determine the onset of pests and diseases related to weather elements.
- To get a step forward for formulation of yield estimation.

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 labor 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.

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 [5].

The Economic development of Punjab largely depends on the progress and growth of Agriculture Sector. The province dominates in overall national agriculture production in major crops: it contributes up to55% in National Rice Production, 65% in National Sugarcane Production, 75% in National wheat Production and 70% in National Cotton Production [6].

1.5 Cotton Production in Pakistan

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. Well-researched 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 Punjab and Sindh in 2010 and 2011 [7].

In Punjab cotton is cultivated on both sides of Indus River. The crop is mainly grown in agricultural plains of central and southern Punjab. The crop is planted in April/May and picking starts in August/September. The crop is harvested in October/November. Total contribution of Punjab is about 70% 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 cultivated and total annual production in the country.

Chapter 2

MATERIALS AND METHOD

The cotton crop FH-Lalazar was cultivated at Regional Agrometeorological Center, Faisalabad in central Punjab during Kharif season 2015. Both the meteorological and crop phenological data were recorded during the crop season. In order to compile the data of each development stage, careful, precise and timely recording of the following parameters (table 2.1) were undertaken at 0300, 0900 and 1200 (UTC) as routine practice.

Table 2.1: Observed Meteorological Parameters

1.	Air Temperature (˚C)
2.	Maximum & Minimum Temperature (˚C)
3.	Soil Temperature (˚C)
4.	Relative Humidity (%)
5.	Precipitation (mm)
6.	Pan Evaporation at 0300 & 1200UTC
7.	Bright Sunshine Hours
8.	Wind Speed (km/hour)
9.	Wind Direction
10.	Soil Moisture (%)

Crop data including Phenological data and soil moisture observation was collected according to World Meteorological Organization (WMO) and Food & Agriculture Organization (FAO) standards.

2.1 Phenology

For a sound understanding of plant growth and development, observation and recording of phenological stages of plant is an essential element (table 2.2). The impact of precipitation, 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. [8]

Table 2.2: Phenological Stages of Cotton Crop 2015

	Phenological stage	Date
1.	Sowing	19-05-2015
2.	Emergence	23-05-2015 To 25-05-2015
3.	Third Leaf	27-05-2015 To 01-06-2015
4.	Budding	13-06-2015 To 29-06-2015
5.	Flowering	08-07-2015 To 19-08-2015
6.	Boll Opening	22-08-2015 To 26-09-2015
7.	Maturity	28-09-2015 To 10-10-2015
8.	First picking	31-10-2015

2.1.1 Phenological Observations

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

Total number of plants in a particular phenological phase at the same time was observed from each replication on every Monday, Wednesday and Saturday and 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 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 or no phase can exist.

2.2 Methodology

In this study the impact of different meteorological/non-meteorological parameters in comparison with the normal (1981-2010), including soil temperature and soil moisture, amount of seed per acre cultivated, time of sowing, fertilizer intake, number and timing of irrigation water added and pest attack/pesticide used over crop growth, development and final yield are discussed.

Chapter 3

RESULTS AND DISCUSSION

In this chapter, variations in meteorological and non-meteorological parameters and their impact on the cotton crop is analyzed along with a brief summary of whole cotton crop's life cycle. Normally the cotton crop takes 140-160 days to get fully mature. The crop is cultivated in the start of April up to the mid of May. In order to investigate the chief causes about variation in the crop's growth, development and yield related to varying weather conditions and some other factors during each phenological stages of cotton crop, different meteorological parameters are studied as well.

Table 3.1: Brief Summary of the Cotton Crop

1	Field size	4 kanal
2	Crop variety	FH-Lalazar
3	Date of Sowing	19-05-2015
4	Information about any disease/pest attack,	White Fly
5	Pesticides And weedicides details	Confidor + Momento and Lysenta + Polo+Match
6	Quantity of seed per acre	10 Kg
7	Row spacing	75cm
8	Schedule and quantity of supplied dose of fertilizer	a- 1.5 bag DAP at sowing b- 2 bag Urea during 1st and 2nd irrigation.
9	Type of irrigation	Flood irrigation
10	Irrigation schedule	27-05-2015 (First irrigation) 12-06-2015 (Second irrigation) 17-06-2015 (Third irrigation) 01-07-2015(Fourth irrigation) 02-09-2015(Fifth irrigation) 15-09-2015(Sixth irrigation) 20-09-2015(Seventh irrigation)
11	Heat units consumed from sowing to full maturity	3013
12	Total days taken by the crop from sowing to full maturity	140
13	Date of First	031-10-2015

	Picking	
14	Actual/ Potential yield	480/600 kg /acre

3.1 Rainfall and Cotton Crop Growth

Rainfall is one of the most important factors that affect annual cotton production in Pakistan. Faisalabad and its surrounding areas of central Punjab get most of its annual rainfall 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 [10].

During the crop season 2015, above normal precipitation was recorded in the months of May, July, September and October. In July precipitation amount to 128.7 mm which was largely above normal (1981-2010). This is due to two very heavy spells during the month. On the other hand precipitation in June and August remained largely below normal. Overall the precipitation remained slightly above normal during the kharif season 2015 at RAMC, Faisalabad.

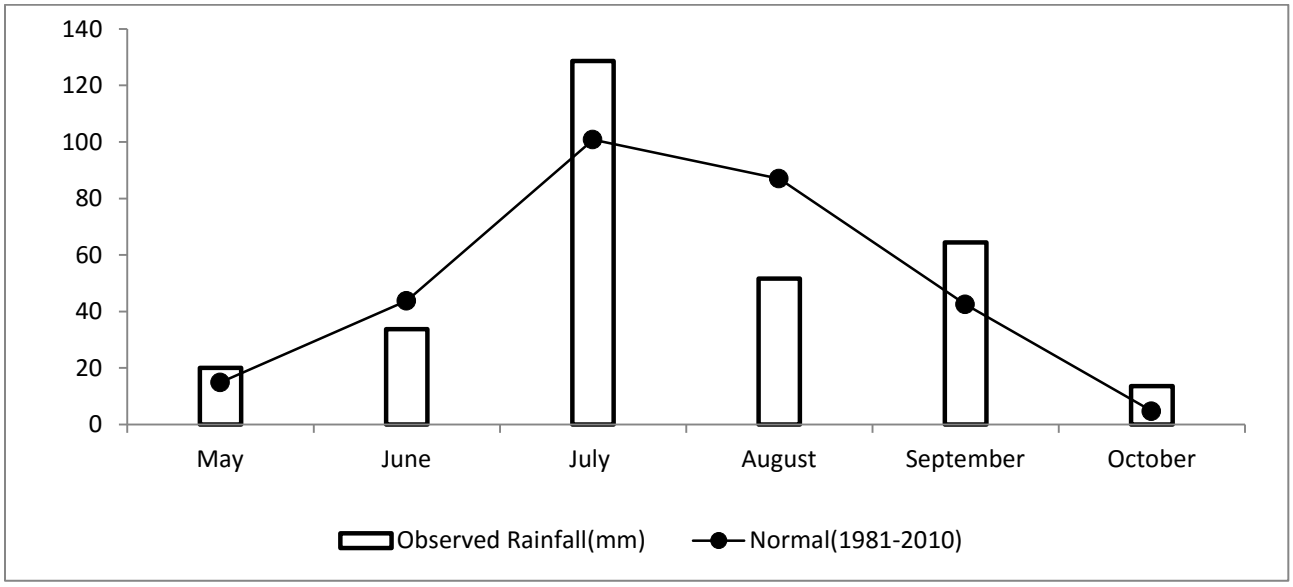

Figure 3.1: Comparison of Monthly observed rainfall with Normal (1981-2010) at Faisalabad during Kharif season 2015.

Table 3.2: Daily Rainfall History of the Crop Life 2015

Year	Phenological stage	Month	Day	Daily Precipitation (mm)	Total Precipitation During Stage (mm)	Monthly Total (mm)
2015	Emergence	May	--	0	0	0
2015	Third Leaf	June	10	2.0	2.0	
2015	Budding	June	15	Tr		
2015	Budding	June	20	29.0		
2015	Budding	June	22	0.3		
2015	Budding	June	24	2.5		
2015	Budding	June	25	Tr		34.4
2015	Budding	July	6	57.0	89.3	
2015	Flowering	July	10	6.2		
2015	Flowering	July	11	Tr		
2015	Flowering	July	13	7.0		
2015	Flowering	July	17	Tr		
2015	Flowering	July	22	Tr		
2015	Flowering	July	23	0.5		
2015	Flowering	July	25	2.0		
2015	Flowering	July	26	54.0		
2015	Flowering	July	30	Tr		
2015	Flowering	July	31	2.0		128.7
2015	Flowering	August	1	8.4		
2015	Flowering	August	2	17.0		
2015	Flowering	August	10	15.0		

2015	Flowering	August	14	Tr		
2015	Flowering	August	15	7.2	119.3	
2015	Boll Opening	August	24	4.0		
2015	Boll Opening	August	27	Tr		51.6
2015	Boll Opening	September	8	2.4		
2015	Boll Opening	September	21	23		
2015	Boll Opening	September	22	39	68.4	64.4
2015	Maturity	October	24	Tr		
2015	Maturity	October	25	13.6	13.6	13.6

3.2 Irrigation during Crop Growth

During kharif season 2015, irrigated water was added to the field 07 times; first irrigation was done 08 days after sowing during third true leaf stage. Remaining irrigations were done during other phenological stages at the time of need. Low amount of rains at the start of the season increase the need for irrigated water at initial phases of the crop but more rains at the middle and end part of the plant biological life minimize the need for irrigated water.

3.3 Air Temperature and Cotton Crop Growth

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. Hence three temperature values for a plant growth are of particular importance.

They are;

- Biological Zero: is the minimum temperature below which plant growth stops. For cotton crop its value is 12°C.
- Optimum Temperature: at which maximum plant growth occurs. For cotton crop its value is 30°C.
- Maximum Temperature: above which the plant growth stops. For cotton crop its value is above 40°C. [10]

Detail of Mean Monthly Air Temperature, Monthly Mean Maximum and Minimum Temperature and Absolute Maximum and Minimum temperature are presented in Table – 3.3 along with Normal (1981-2010) values and is also shown in following figures (3.2 – 3.4).

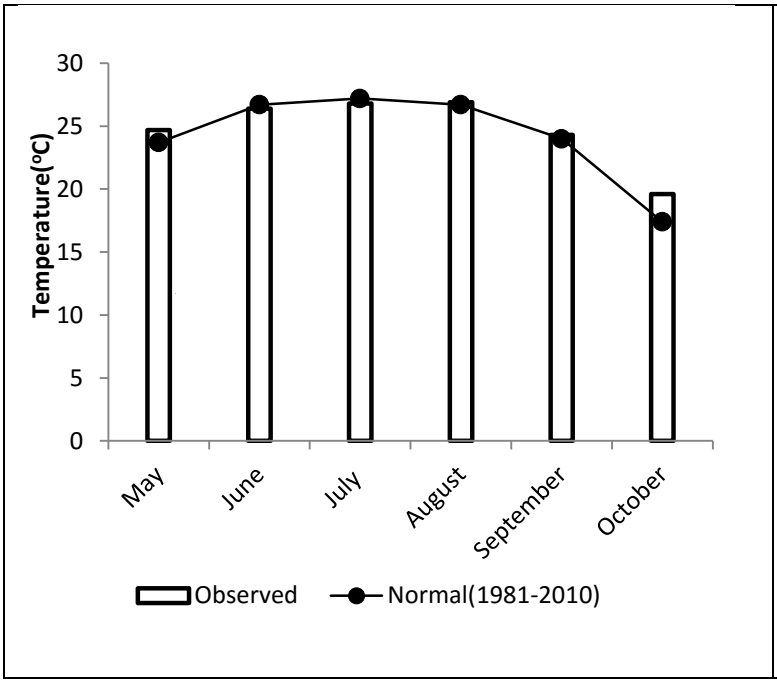

Figure3.2: Mean daily Minimum Temperature (°C) of Faisalabad during the Kharif Season

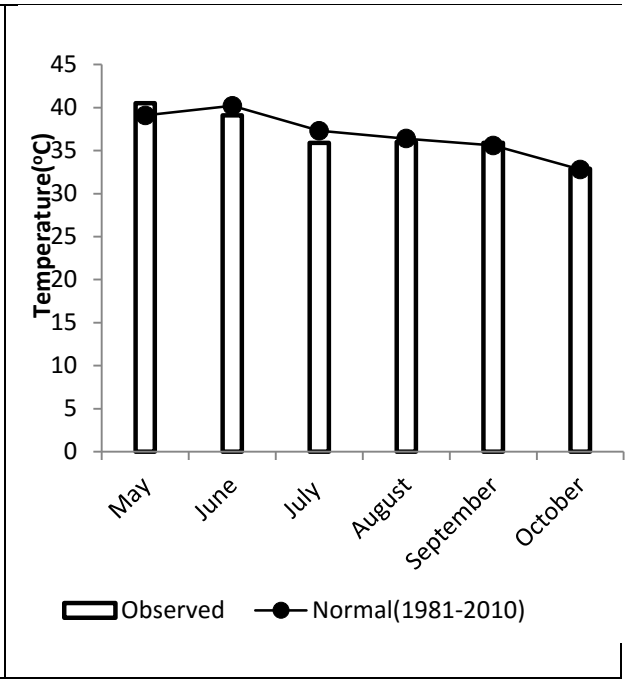

Figure3.3: Mean daily Maximum Temperature (°C) of Faisalabad during the Kharif Season

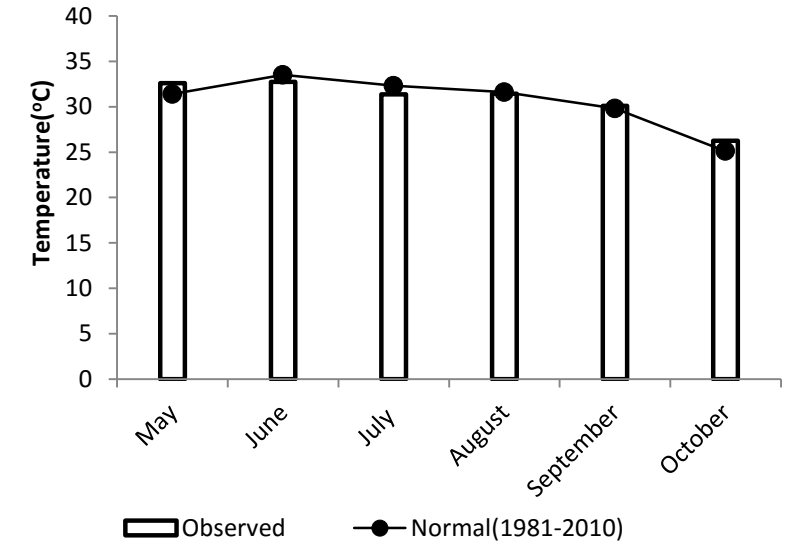

Figure 3.4: Mean Monthly Temperature during Kharif Season 2015

During the crop season of 2015 both mean daily temperature and day time maximum temperature observed to be remained normal during most of the crop life. Very slight variation from normal was experienced from normal which is a good factor for crop growth.

Table3.3: Mean Monthly Temperature during Kharif Season 2015

Month	Mean Monthly (°C)	Monthly Mean Max.(°C)	Monthly Mean Min(°C)	Absolute Max. (°C)	Absolute Min. (°C)
May-2015	32.6 (30.6)	40.5 (38.4)	24.7 (22.7)	44.5 (48.0)	19.0 (13.0)
Jun-2015	32.8 (33.7)	39.1 (40.5)	26.4 (26.9)	44.0 (48.0)	22.0 (17.0)
Jul-2015	31.3 (32.3)	35.9 (37.1)	26.8 (27.1)	41.5 (47.0)	22.8 (19.0)
August-2015	31.7 (32.3)	36.0 (36.1)	26.9 (26.6)	38.7 (42.0)	21.0 (18.6)
Sept-2015	30.2 (29.7)	35.9 (35.7)	24.3 (23.7)	39.0 (43.0)	21.0 (16.0)
Oct-2015	26.3 (25.0)	32.9 (33.0)	19.6 (17.0)	37.0 (40.0)	12.5 (08.0)

( ) in Table 3.3 shows Normal values (1981-2010)

3.4 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. Highest amount is needed during flowering stage followed by grain formation stages and then vegetative stages [11].

To calculate soil moisture, soil samples are taken on 7^{th}, $17^{th}$and 27^{th} of each month in four replications at 5, 10, 20, 30, 40, 50, 70 and 90 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:

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

Moisture contents of the soil varied due to dry and wet spells throughout the season. After each effective irrigation or rain the moisture level increased in the shallow layers as compared to deep layers of the soil.

During the crop season 2015, from the observed soil moisture data, figures(3.5 – 3.11)depicts that soil moisture remained satisfactory during initial and final stages of the crop life whereas it remained slightly deficit during middle stages (August & September) due to seasonal rise in direct solar radiation. But due in time irrigation during the crop growth remained mostly normal throughout the crop life. Rainfall reported during the crop life also fulfilled soil moisture requirement.

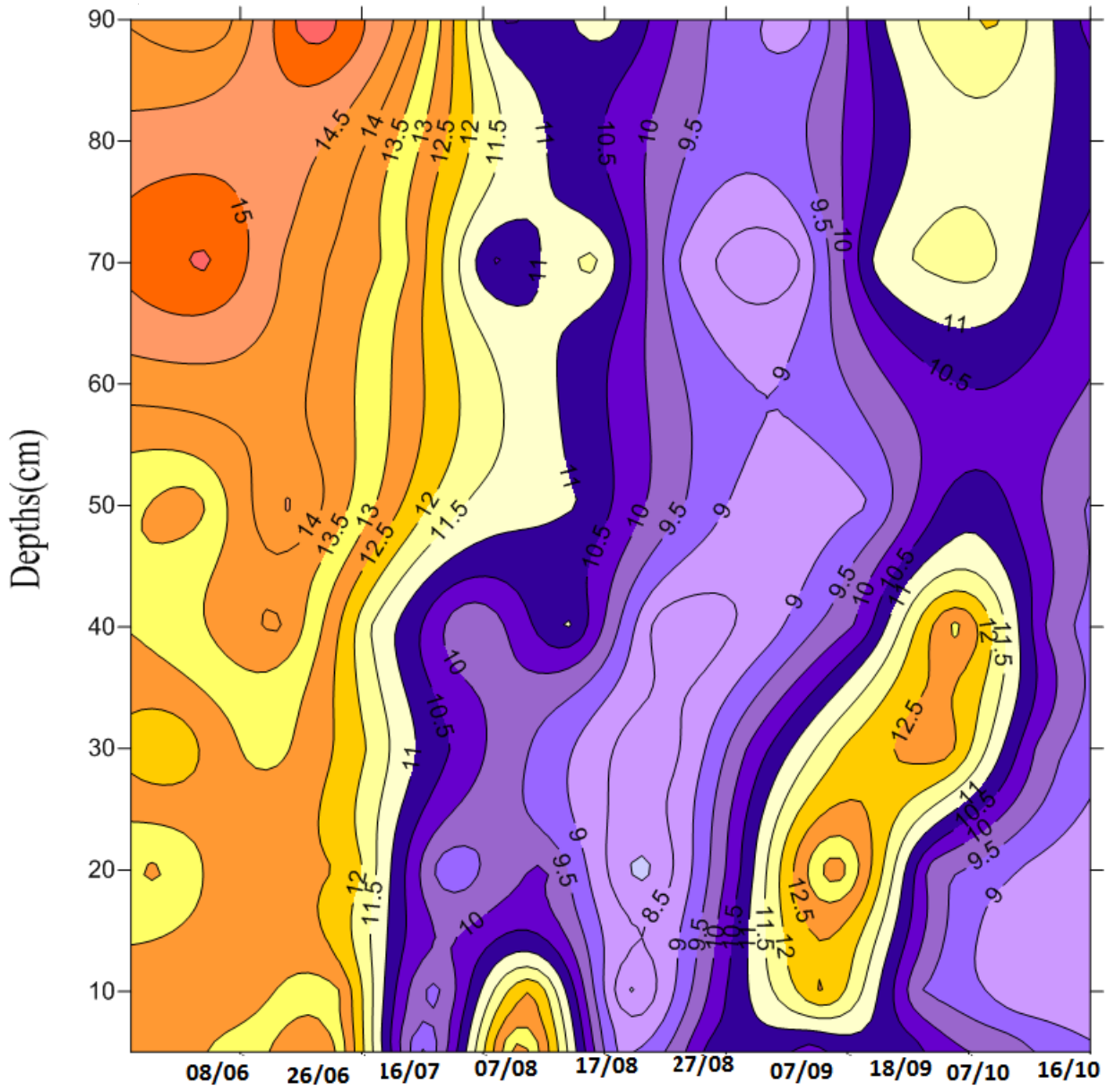

Figure 3.5: Soil moisture chrono Isopleths for Kharif Crop at Faisalabad for the year 2015.

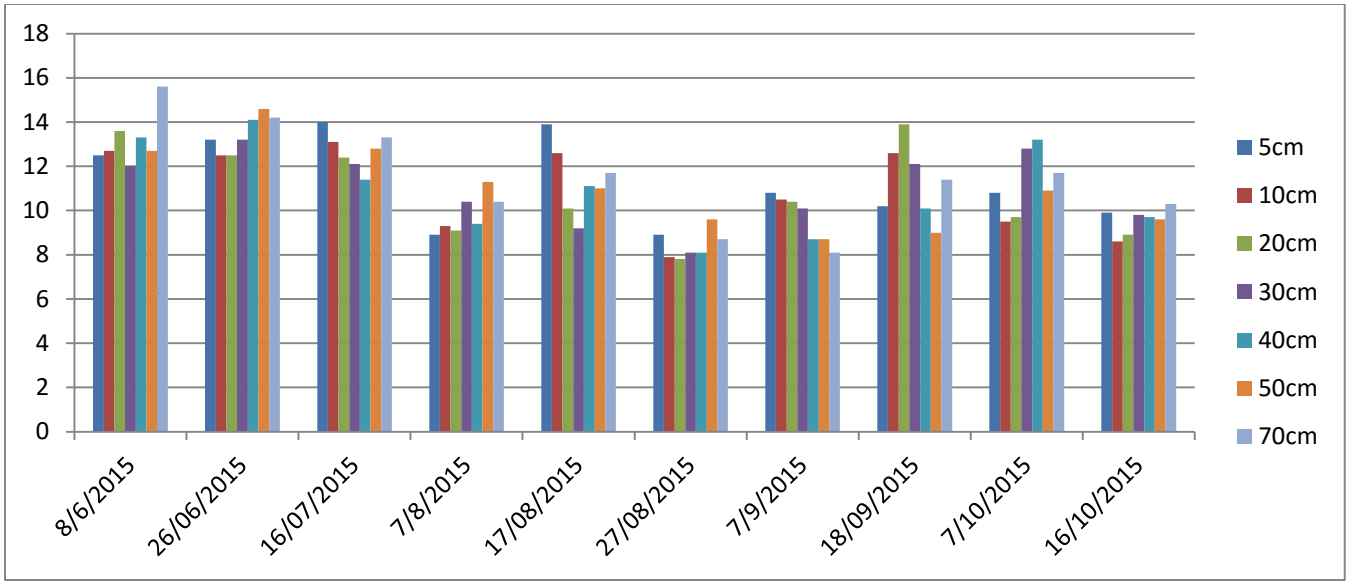

Figure3.6: Soil moisture at different depths during Cotton crop 2015.

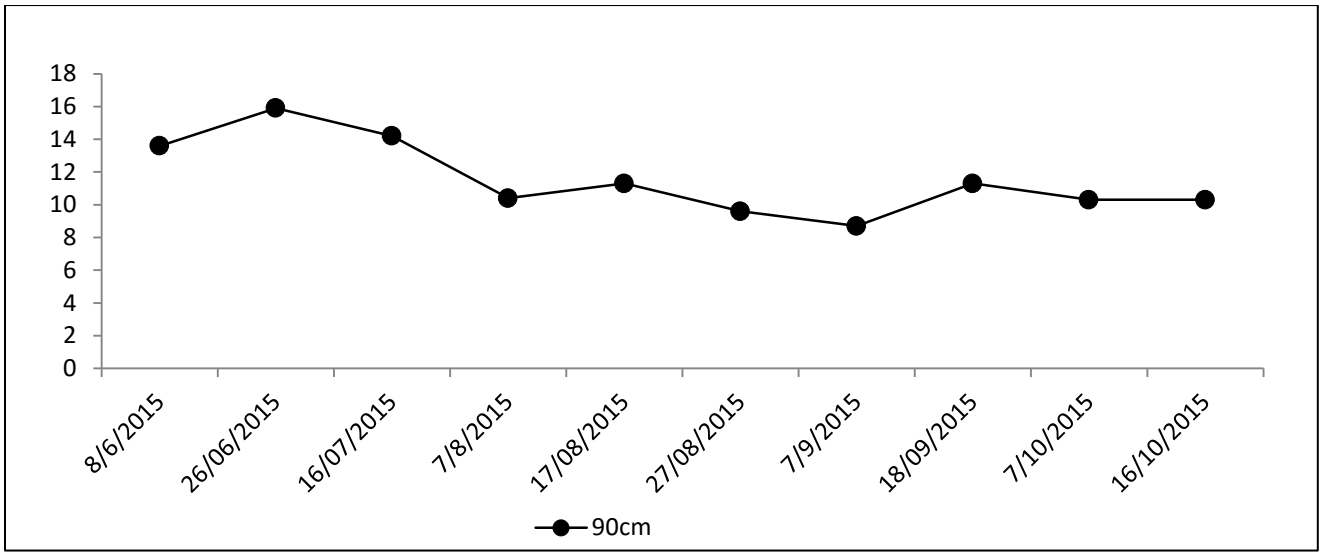

Figure 3.7: Soil moisture at deep soils (90cm) during Cotton crop 2015.

3.5 Soil Temperature and Crop Growth

Soil temperature is the most important parameter affecting growth of the crop. Plants roots are very sensitive to the soil temperature. In comparison to air temperature, the amplitude of variation in soil temperature is much more pronounced because of the varying characteristics, texture, composition, and organic material 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. The daytime soil temperature is more important than the nighttime temperature, because it is necessary to maintain the internal crop water status to match the evaporation rate. Optimal soil temperature for the germination of cotton plant is 15.5°C. [10]

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

From the observed data, it is evident that generally, soil temperature increases gradually with increasing depths. Soil temperature varies as soil moisture varies from depth to depth and time to time. To measure soil temperature, the soil thermometers were installed at different depths to monitor the thermal regime of the soil. The soil temperatures in degree Celsius (℃) were observed and then recorded three times a day at 0300, 0900 and 1200 UTC. The depth at which the soil temperatures were observed on daily basis includes 5, 10, 20, 30, 50 and 100 cm depths. It was observed that major root concentration centered between 30cm to 40 cm.

Note: This soil temperature data is collected from the soil observations taken at Agromet observatory of RAMC Faisalabad 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 2015, soil temperature remained highest during June at all depths except at the deep layer of 100 cm which remained warmest in September and coolest in May.

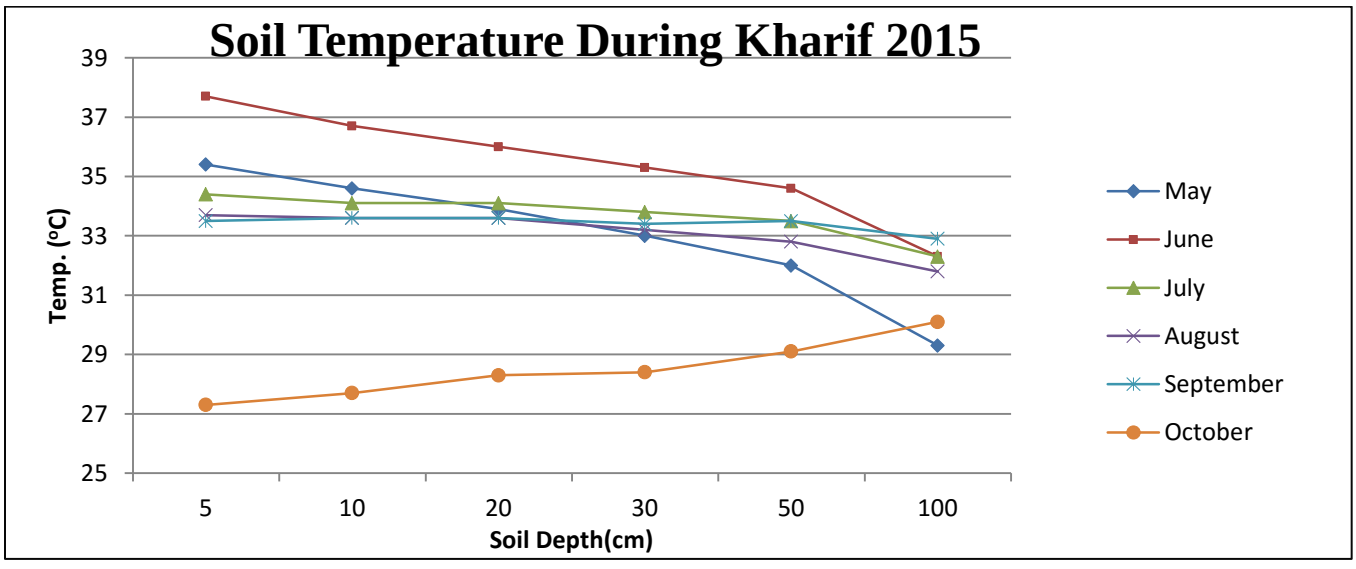

Figure 3.8: Soil temperature during Cotton crop 2015.

3.6 Heat Units Consumption during Crop Cycle

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

The heat unit concept assumes a direct and linear relationship between plant growth and temperature. It starts with the assumption that total plant growth is dependent on the total amount of heat to which it is subjected during its life time. The heat units for a particular crop on any day are the difference between the daily mean temperature (T) and the base temperature (Tb) of the crop. Base temperature or Biological zero is the minimum temperature below which no growth occurs. The base temperature or threshold varies with different plants, and for the majority it ranges from 4.5 to 12.5°C.Here for cotton crop base temperature is 12°C. This concept assumes that a given cultivar requires the same summation (k) of the daily mean temperature for going one phenological stage to next stage, regardless of temperature distribution. Generally only positive values above the biological zero (Tb) are considered. The period of negative value is termed as "dormant" because crop does not grow under such conditions.

In this study the effective method has been used for determining heat units which is represented by the following equation.

$$GDD = \sum(T - Tb) = k \quad if\ T > Tb \text{ and } GDD = 0 = k \quad if\ T < Tb$$

where***T***= Mean daily temperature, ***Tb*** = Biological Zero (5°C),***k***= Heat Unit [10].

InterPhase period for cotton crop during 2015 and corresponding heat units at RAMC Faisalabad observed at different phenological stages varies from phase to phase. Heat unit requirements of different phases and cumulative heat units for the crop have been worked out, are shown in figure 3.9 and Table–3.3. Total heat units consumed by the cotton crop were 3013 accumulated from germination to full maturity in 140 days. On average 21.5 heat units were consumed by the crop per day. Normally these heat units are consumed in 150 days at the rate of 18.5 heat units per day, which shows that the crop reached to full maturity almost in normal thermal time. From figure 3.9 it is clear that crop consumed normal to below normal heat units during the vegetative stages of emergence and boll opening. However during budding and flowering above normal heat units were consumed so that these phases completed earlier than normal time.

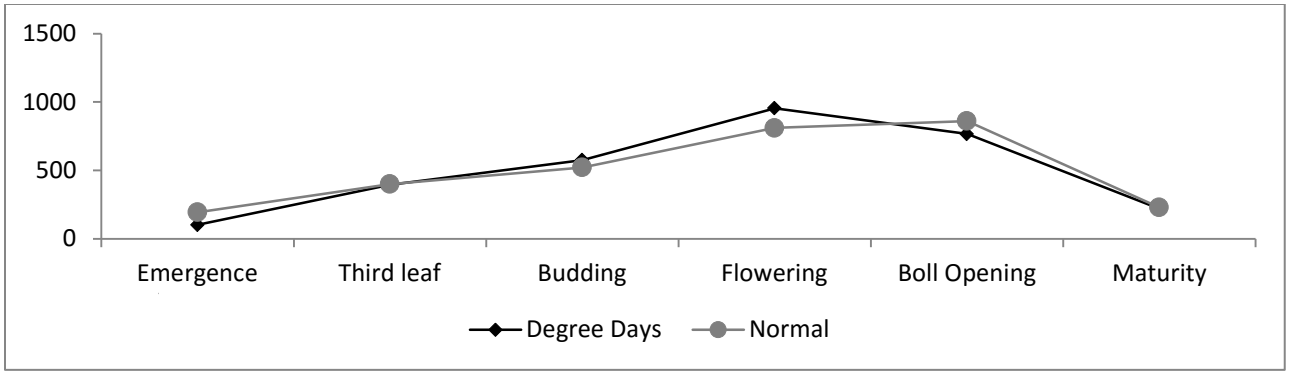

Figure 3.9: Heat units during crop life 2015.

Table 3.4: Heat Units Consumed by the Crop during Different Phenological Phases

S. No.	Inter Phase	Period	No. of Days Taken	Degree Days (T-10℃)	Normal Degree Days
1	**Date of Sowing**	19-05-2015	--	--	--
2.	**Emergence**	23-05-2015 To 26-05-2015	4	102	194
3.	**Third leaf**	27-05-2015 To 12-06-2015	16	395	400
4.	**Budding**	13-06-2015 To 07-07-2015	25	576	522
5.	**Flowering**	08-07-2015 To 21-08-2015	45	954	811
6.	**Boll Opening**	22-08-2015 To 27-09-2015	37	766	861
7.	**Maturity**	28-09-2015 To 27-09-2015	13	220	229
8.	**First Pick**	31-10-2015	--	--	--
9.	**Emergence to Maturity**	23-05-2015 To 27-09-2015	140	3013	3017

3.7 Relative Humidity (%)

Relative humidity (RH) is simply defined as the ratio of the actual amount of water vapor (grams) in the unit mass of air at a given temperature to the mass of water vapor in the same sample of air when it is saturated at the same temperature. RH tells us about how much a sample of air around the observing

station is saturated. It is expressed in percentage. For example if relative humidity of the atmosphere is 60%. It means that 60% of the atmosphere is saturated with water vapor or moisture and 40% of the present moisture may be added more to saturate (100% RH) the atmosphere. RH is temperature and moisture dependent and may vary if moisture content or temperature of the atmosphere is changed. It is always inversely proportional to temperature and ETo. RH is calculated with the help of dry bulb and wet bulb temperatures fitted in the Stevenson screen.

3.8 Reference Crop Evapotranspiration, ETo (mm/day)

Reference Crop Evapotranspiration or ETo is defined as the rate of Evapotranspiration from an extended surface of 8– 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground, free from disease and not short of water. The standard method of calculating ETo is revised Penman-Monteith equation. Using this method, ETo is calculated using data of temperature (maximum and minimum), wind speed, relative humidity and solar radiation. Solar radiations are calculated with the help of total bright sunshine hour data at a particular station. Sunshine duration recorders with sunshine cards are used for sunshine hours recording [11].

During the crop season 2015, relative humidity remained normal, whereas, ETo remained normal to below normal during most of the growing period. Below normal EToduring vegetative stages of the crop did not produce any harmful effects on crop growth due to in time irrigation. Overall soil and air moisture content was favorable for crop growth.

3.9 Wind and Crop Growth

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 2015, no such bad weather event was observed. Wind speed was observed mostly below normal and any significant wind speed accompanied by any severe weather event was not observed throughout this period.

Table 3.5: Summary of some Meteorological Parameters during Kharif Season 2015

Month	Wind speed (km/hr)	RH(%)	Days with mean RH ≥80%	ETo (mm/day)
May-15	3.2(4.6)	38(37.0)	0	6.55
Jun-15	4.3 (6.4)	45 (49.1)	0	6.88
Jal-15	4.8 (6.0)	67 (61.0)	0	5.52
Aug-15	3.8 (4.0)	66 (66.0)	0	5.59
Sep-15	2.8 (2.5)	55(60.0)	1	4.98
Oct-15	2.0 (1.7)	54 (55.0)	1	3.69

3.10 Crop Water Requirement (CWR)

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:

Water Requirement is mainly dependant on climatic factors such as air temperature, solar radiation, relative humidity, wind velocity etc. and agronomic factors like stage of the crop development as well.

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 [12].

3.10 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 1 during the boll opening 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 wax maturity. A schematic variation of the crop coefficient related to different crop development stages under normal conditions is given in figure 3.10.

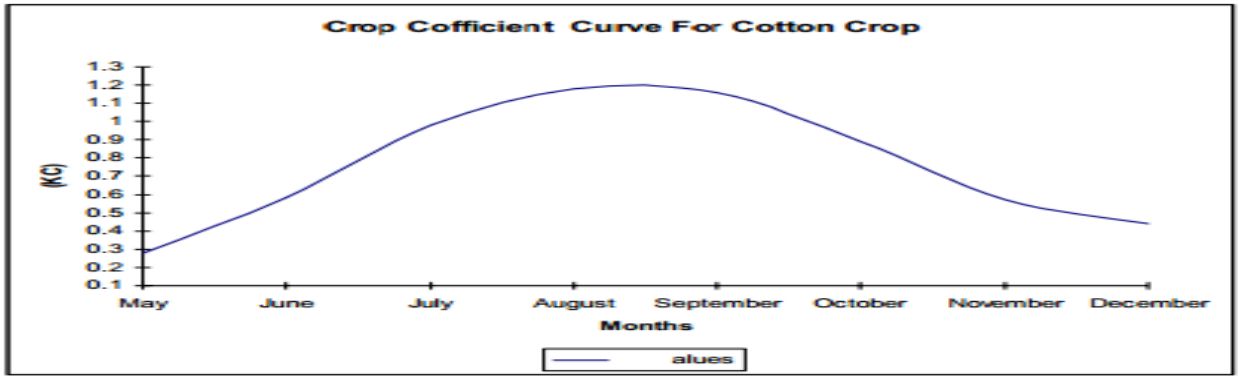

Figure 3.10: March of Crop Coefficient (Kc) for normal duration of Cotton growing season (Emergence to Wax- Maturity).

The water requirements can be calculated in millimeters and they can be converted into cubic meter per hectare by following equation:

10 mm = 1 cubic meter per hectare

Along with the loss of water through evaporation and transpiration, the compensation of this loss by precipitation may also be considered. Normally most of the plants grow successfully and utilize water for the soil at 50% and above available soil moisture. The maximum demand (daily or seasonal) may be equal to the reference crop evapotranspiration (ETo) which is utilized through soil moisture . It is observed that crop water requiremnt has quantitatively increased due to increasing temperature trend [13].

During the Kharif Season 2015 in Faisalabad, crop water requirement of cotton crop was observed normal to below normal throughout the crop growth except at flowering stage. (Fig 3.11& Table 3.6). It means that crop growth did not suffer due to sharp rise in crop water demand expect at flowering. Thus the available irrigated and rain water satisfied moisture requirement of the crop, which resulted normal crop growth.

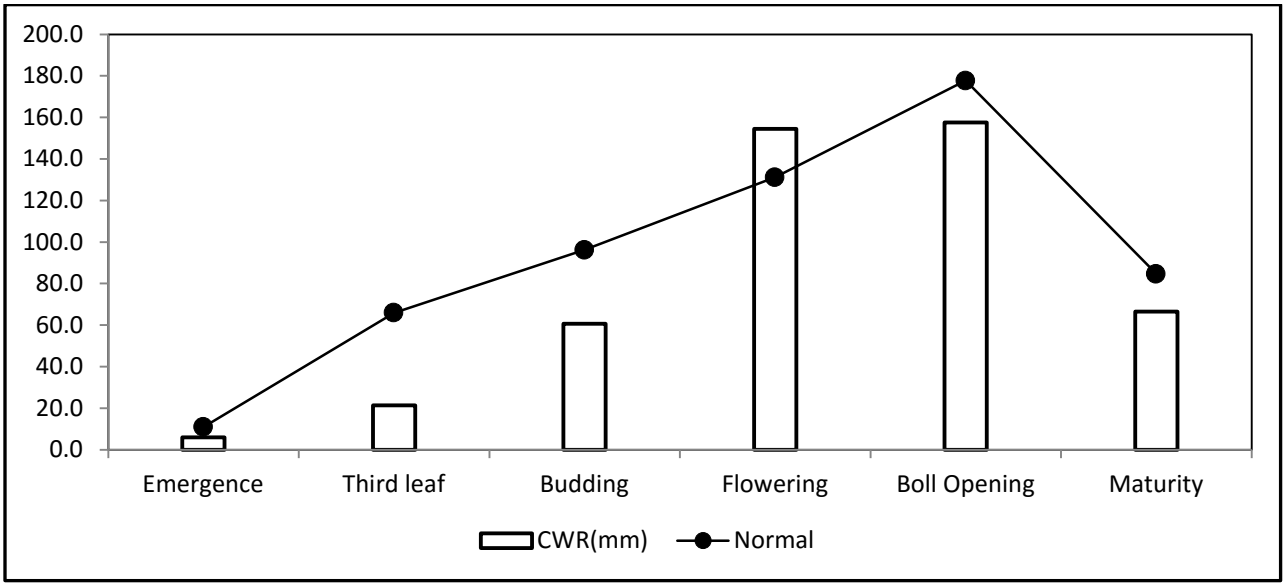

Figure3.11: Crop Water Requirement (CWR) During Crop Life.

Table 3.6: Crop water requirement during different phenological phases

S. No.	Inter Phase	Period	No. of Days Taken	ETo (mm)	*ETo (mm)	CWR=Kc ETO	CWR=Kc *ETO
1.	**Emergence**	23-05-2015 To 26-05-2015	4	21.2	39	5.9	10.9
2.	**Third leaf**	27-05-2015 To 12-06-2015	16	76.3	135.2	21.4	65.9
3.	**Budding**	13-06-2015 To 07-07-2015	25	119.3	139.6	60.6	96.2
4.	**Flowering**	08-07-2015 To 21-08-2015	45	182.2	134.1	154.4	131.2
5.	**Boll Opening**	22-08-2015 To 26-09-2015	37	147.6	148.1	157.6	177.7
6.	**Maturity**	28-09-2015 To 27-09-2015	13	40.8	70.5	66.4	84.6
7.	**Emergence to Maturity**	28-09-2015 To	140	587.6	666.5	466.3	566.5

		10-10-2015					

*Normals based upon 1991-2010 data.

3.11 Agro Meteorological Summary of Crop Cycle

Different meteorological parameters were recorded at various phases of cotton crop during 2015. The impact of these parameters at different phenological stages of cotton crop is discussed as under.

3.11.1 Sowing

Cotton crop was sown around the mid of May which is slightly late than suitable time for sowing. The mean day temperature was slightly above than normal values and there was no rain after sowing. Night temperatures were also slightly higher than normal values.

3.11.2 Emergence

Emergence phase was distinguished by the appearance of spike above the ground. When plant emergence stage was completed; the field was divided into four replications. The mean relative humidity during this phase was 38%. Mean air temperature during emergence was 36.1°C.Dry weather was reported during this stage. But crop growth reported excellent during this stage.

3.11.3 Third Leaf

This phase took 6 days to complete. The mean relative humidity was 34%; mean air temperature was 32.7°C. Precipitation of amount 2mm was recorded during this phase. Excellent crop growth was reported during this stage.

3.11.4 Budding

The bud is in the shape of three walled pyramid and lighter in colour than the plant leaves. This phase is considered established when the bud is 3-5 mm in size. The mean air temperature during this phenological stage was 33°C and mean relative humidity was 49%. This phase experienced large amount of precipitation i.e 89.3 mm which also include a spell of 57mm rainfall on 6th of July 2015.

3.11.5 Flowering

The mean air temperature during this stage was recorded as 31.1°C and mean relative humidity was 70%. This long duration phase experienced a significant amount of precipitaion of 119.3mm which negatively affected the crop. The increase in humidity also triggered the pest and disease attack on the crop.

3.11.6 Boll Opening

This phase is established when the opening of the top of the boll is one centimeter long and the cotton fibers are visible through the opening. The mean air temperature was 30.7°C during this phase. The relative humidity was 56%. Precipitation of 68.4mm was reported during this phase. A spell 62mm rainfall in two days badly damaged the final yield of the crop.

3.11.7 Maturity

This phase is established when the lint hairs have dried and turned into fez and can be easily detached from the boll. The mean air temperature was recorded as 28.9°C whereas mean relative humidity during this phase was 50%. This stage experienced 13.6mm of rain.

3.11.8 First Pick

First pick of the cotton crop was done on 31-10-2015. It was also late as the maturity was completed 10-10-2015.

Chapter 4

CONCLUSION AND RECOMMENDATIONS

The crop variety FH-Lalazar was cultivated in the experimental field of Ayub Agriculture Research Institute Faisalabad. The sowing time is a very important factor. The time of sowing is directly related to yield of the crop.

According to Table – 3.1 and Chapter-3 (Results and Discussion),the crop was sown slightly later than the proper time. Amount of seed cultivated per acre was 10 kg which is sufficient for the crop cultivated in May. Fertilizer intake was also enough i.e., 1.5 bag of DAP and 2 bags of Urea. No rainfall was reported in May but Rainfall amounting 34.4mm was reported in June. July received 128.7mm of precipitation which was also largely above normal. Cotton was in flowering stage during this month. Above normal rainfall was again experienced in the month of September which badly effect the crop yield. Irrigation was made 7 times during the season which mostly fulfilled the water requirement of the crop.Day and night time temperatures were observed to around normal range. RH was also observed to be normal throughout the crop life except in July when large amount of rain increased its value to above normal. However ETo remained below normal during most of the crop's growth period. As a result normal moisture content of soil in major root zone was observed during most of the crop life thus contributing to normal crop's growth, development. Air and soil temperature regime remained normal for most of the crop's period, which also favored crop growth at all stages. Total heat units consumed by the cotton crop were 3013 accumulated from germination to full maturity in 140 days. On average 21.5 heat units were consumed by the crop per day. Normally these heat units are consumed in 150 days at the rate of 18.5 heat units per day, which shows that the crop reached to full maturity almost in normal thermal tim. From figure 3.9 it is clear that crop consumed normal to below normal heat units during the vegetative stages of emergence and boll opening. However during budding and flowering above normal heat units were consumed so that these phases completed earlier than normal time.

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 2015 recommended weedicides operations were performed in time, which also reinforced crop's growth and production. Due to favourable temperature and humidity values pest attack was observed on the crop during its life cycle. Especially white fly attack was very severe and prolonged. Pesticides were used for its control.

4.1 Conclusions

During the kharif season 2015, most of the air and soil weather parameters like air and soil temperature, rainfall, irrigation with suitable intervals, R.H and crop water requirement favored normal to above normal crop growth. The crop was cultivated slightly late but with normal fertilizer doze and weeds removing spray at suitable intervals. However heavy precipitation spell at the time of flowering and maturity affected adversely the crop which eventually resulted below potential yield of the crop.

4.2 Recommendations

Keeping above results and conclusions, following recommendations/suggestions are given to farmers and other related personals to enhance cotton crop yield in central Punjab 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 central germination, smaller heads, shriveled boll and central 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 central Punjab is 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 during 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 fcentrals 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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