Weather and Wheat Crop Development in Potohar Region Punjab (Rawalpindi) (2015 – 2016)

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Summary

This study was conducted at RAMC (Regional Agrometeorological Center) Rawalpindi to investigate the impact of weather conditions on the growth and development of wheat crop. Impact of variations in the meteorological parameters on different phenological phases and hence on final yield of wheat crop was analyzed. For this purpose, both meteorological and phenological data was collected from the meteorological observatory and agricultural field of physiology section of Arid agriculture university, Rawalpindi. Besides this record, other necessary features like sowing time, fertilizer, weeds removing operations, amount and frequency of rainfall are also included in the current report for the Rabi season 2015-16. The wheat crop variety Chakwal 97 sown in the field under observation used 2270 heat units in 159 days during its life cycle from sowing to full maturity. The water requirement of crop was fulfilled by rainfall. Weather during crop growth period was generally suitable for crop. Normal to slightly above normal air temperature during the grain formation stages provide the grain enough heat to grow. The crop was sown slightly late in the proper time and the rainfall in April and May during very crucial crop growing stages i.e. milk maturity to full maturity, affected the crop and slightly below potential yield was received.

Chapter 1

INTRODUCTION

Wheat is the major food crop as well as one of the main agricultural products in Pakistan. This study is based upon field observations of wheat crop at Regional Agrometeorological Centre, Rawalpindi cultivated in the experimental field of Arid Agriculture University, Rawalpindi. In experimental field wheat crop variety Chakwal 97 was cultivated. This study will help in understanding the effect of different climatic parameters on the growth and yield of wheat crop in Potohar region.

1.1 Geographical Description and Climate of Potohar region (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 Rasul found that about 2/3 of the total agriculture area lies in the arid climate. [1]

The study has been conducted for “Rawalpindi region” in the Potohar Zone with longitude 73.07^{o}E, latitude 33.6^{o}N and elevation of 517m from mean sea level. The climate of Northern Punjab including Potohar region has a considerable temperature variations resulting in creating favorable conditions for extreme weather patterns (Figure – 1.1). However summer monsoon produces more rainfall as compared to winter. 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 Rawalpindi during Rabi season is shown in the figures (1.2 & 1.3). The highest amount of rainfall occurs during Rabi season in the month of March followed by January and February. Day time mean maximum and night time mean minimum temperatures gradually increases from December onwards. [3]

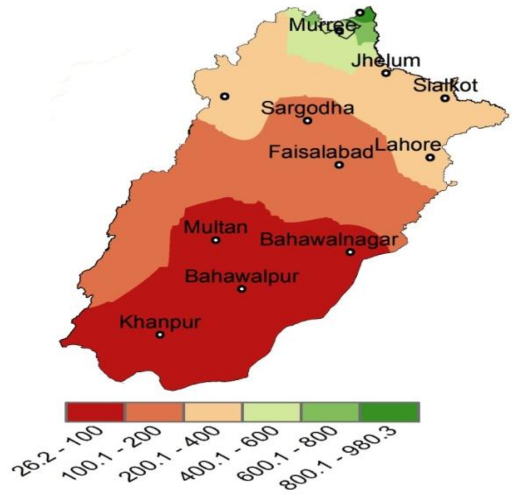

Figure 1.1: Mean Annual Rainfall (mm) of Punjab [Normal (1981-2010)]

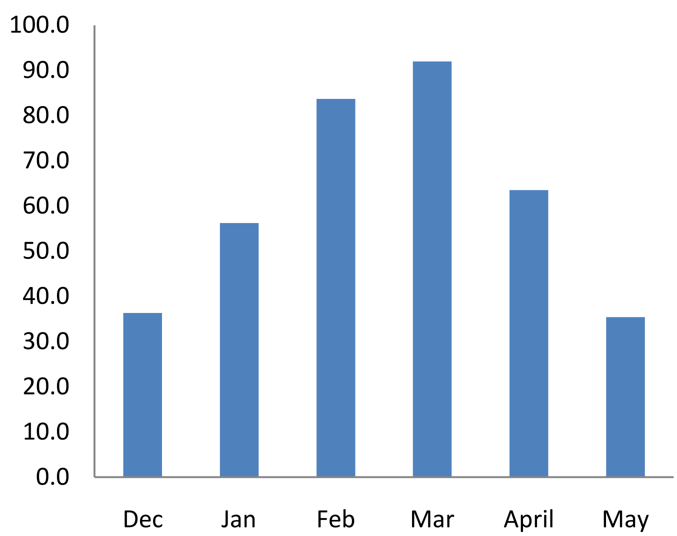

Figure 1.2: Monthly Mean Annual Rainfall (mm) of Rawalpindi (Normal 1981-2010) during Rabi Season

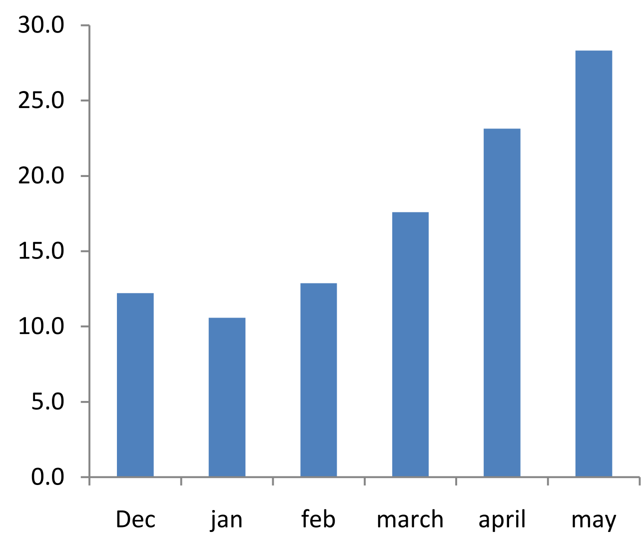

Figure 1.2: Monthly Mean Annual Temerature (°C) of Rawalpindi (Normal 1981-2010) during Rabi Season

1.2 Scope of the Study

Pakistan experiences a more variable and unpredictable behavior of weather systems as compared to other countries of the region. This type of weather patterns result in the variations in the amount of available water both for irrigated and rain fed agricultural lands, which consequently results in the fluctuations in annual yield of wheat. Some time heavy rains along with persistent cloudy conditions trigger the viral or pest attack on wheat crop and also cause rapid growth of weeds in the fields. It also prolongs the crop period, which causes delay in sowing of next Kharif crop. Rain just after sowing causes decrease in the number of germinated wheat seeds and also at the time of harvesting/threshing badly damage the final yield. Abnormal rise in day time temperature or late sowing raises crop water requirement at a particular phase. This could also cause early completion of phase and early maturity of grains. Due to which shriveled grain is obtained. Therefore, in this study the impacts of variations of meteorological parameters along with variations in soil temperature and moisture are 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 Rawalpindi 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

Pakistan is an agrarian country whose population and economy directly or in directly (70% directly and 16% indirectly) depends upon agriculture. Agriculture is the mainstay of Pakistan's economy. It accounts for 21% of the GDP and together with agro-based products fetches 80% of the country's total export earnings. More than 44% of the labor force is engaged in this sector. [4] The crops is most vibrant sub-sector of agriculture, it consist of 40% of agriculture and 8% of GDP. Therefore any change in agricultural productivity creates 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. [5]

Punjab contributes about 76% to annual food grain production in the country. According to the Punjab Agriculture department "Punjab has 57% of the total cultivated and 69% of the total cropped area of Pakistan. [6] It provides about 83% of cotton, 80% of wheat, 97% fine aromatic rice, 63% of sugarcane and 51% of wheat to the national food production. Among fruits, mango accounts for 66%, citrus more than 95%, guava 82% and dates 34% of total national production of these fruits. [7]

1.5 Wheat Production in Pakistan

Wheat flour or "Atta" is the common food for most Pakistanis, supplying 72% of caloric energy in the average diet. It is the main food cereal crop in Pakistan and is essentially better from nutritional point of view then most of the cereals and other foods. It is estimated that in our country wheat consumption per capita is 124 kg per year, which is the highest amount over the world. [5] The above fact reflects the importance of wheat crop for our country. Therefore every year variation in the total yield of wheat due to several factors including climate and weather variations directly affects the economy and social balance of the country.

Wheat is a Rabi crop that is grown in the winter season. In Pakistan sowing of wheat takes place from October to December and harvesting during the month of March to May. In Punjab sowing months of wheat are November and December whereas harvesting period is April and May.

Chapter 2

MATERIALS AND METHOD

The wheat crop variety Chakwal 97 was cultivated at Regional Agrometeorological Center, Rawalpindi in Potohar region during Rabi season 2015-16. 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, 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 Wheat Crop 2015-16

	Phenological stage	Date
1.	Sowing	12-12-2015
2.	Emergence	22-12-2015 To 03-01-2015
3.	Third Leaf	04-01-2016 To 14-01-2016
4.	Tillering	15-01-2016 To 28-01-2016
5.	Shooting	29-01-2016 To 17-02-2016
6.	Heading	18-02-2016 To 08-04-2016
7.	Flowering	09-04-2016 To 27-04-2016
8.	Milk Maturity	28-04-2016 To 11-05-2016
9.	Wax Maturity	12-05-2016 To 24-05-2016
10.	Full Maturity	25-05-2016 To 28-05-2016

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 alternate week days 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, amount of seed per acre cultivated, time of sowing, fertilizer intake, number of days and amount of rainfall water added and pest attack/pesticide used over crop growth, development and final yield are discussed.

The observed meteorological data at RAMC Rawalpindi is used in this study. The observations were made at 0300z, 0900z and 1200z as per recommended procedure. Phenological observations on daily basis were also collected from the field of Arid Agriculture University Rawalpindi. The location of field is at Pir Mehr Ali Shah Arid Agriculture University Rawalpindi. The distance of the selected field is approximately 0.5 Km from Regional Agromet Center. So the meteorological parameters which were observed in Agromet Center are same at that particular field.

Chapter 3

RESULTS AND DISCUSSION

In this chapter, variations in meteorological and non-meteorological parameters and their impact on the wheat crop is analyzed along with a brief summary of whole wheat crop's life cycle. Normally the wheat crop takes 100-120 days to get fully mature. The crop is cultivated in the start of November up to the mid of December. 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 wheat crop, different meteorological parameters are studied as well.

Table 3.1: Brief Summary of the Wheat Crop

1	Field size	4 kanal
2	Crop variety	Chakwal 97
3	Date of Sowing	12-12-2015
4	Information about any disease/pest attack, Pesticides/ weedicides details	No pest attack reported and no pesticides were used.
5	Quantity of seed per acre	50 Kg
6	Row spacing	25 cm
7	Schedule and quantity of supplied dose of fertilizer	a- 1 bag DAP & half bag Urea at sowing b- 1 bag Urea at shooting & 1 bag at flowering
8	Type of irrigation	Rainfed
9	Heat units consumed from sowing to full maturity	2270
10	Total days taken by the crop from sowing to full maturity	159
11	Date of harvesting	30-05-2016
12	Actual/ Potential yield	45/60 mounds/acre

3.1 Rainfall and Wheat Crop Growth

Rainfall is one of the most important factors that affect annual wheat production in Pakistan. In time or effective rainfall i.e., before sowing and shooting to grain formation stage is greatly beneficial. In the same way, rain after sowing and before germination and at the time of full maturity negatively affect crop growth and ultimately reduce the yield. [9]

During the crop season 2015–16, rainfall amounting 20.0 mm was reported for a day in December, 55.7 mm for 05 days in January during early to mid growing stages. In the month of February, below normal rainfall amounting 46.3 mm was reported for 03 days during tillering/shooting stages. In March above normal heavy rainfall amounting 180.1 mm for 12 days was reported during shooting stage. During April rainfall amounting 15.1 mm for 08 days reported from shooting to flowering stages. Whereas rainfall amounting 26.0 mm for 04 days was recorded in May during flowering to maturity stages. Overall below normal rainfall was received during the crop season 2015-16.

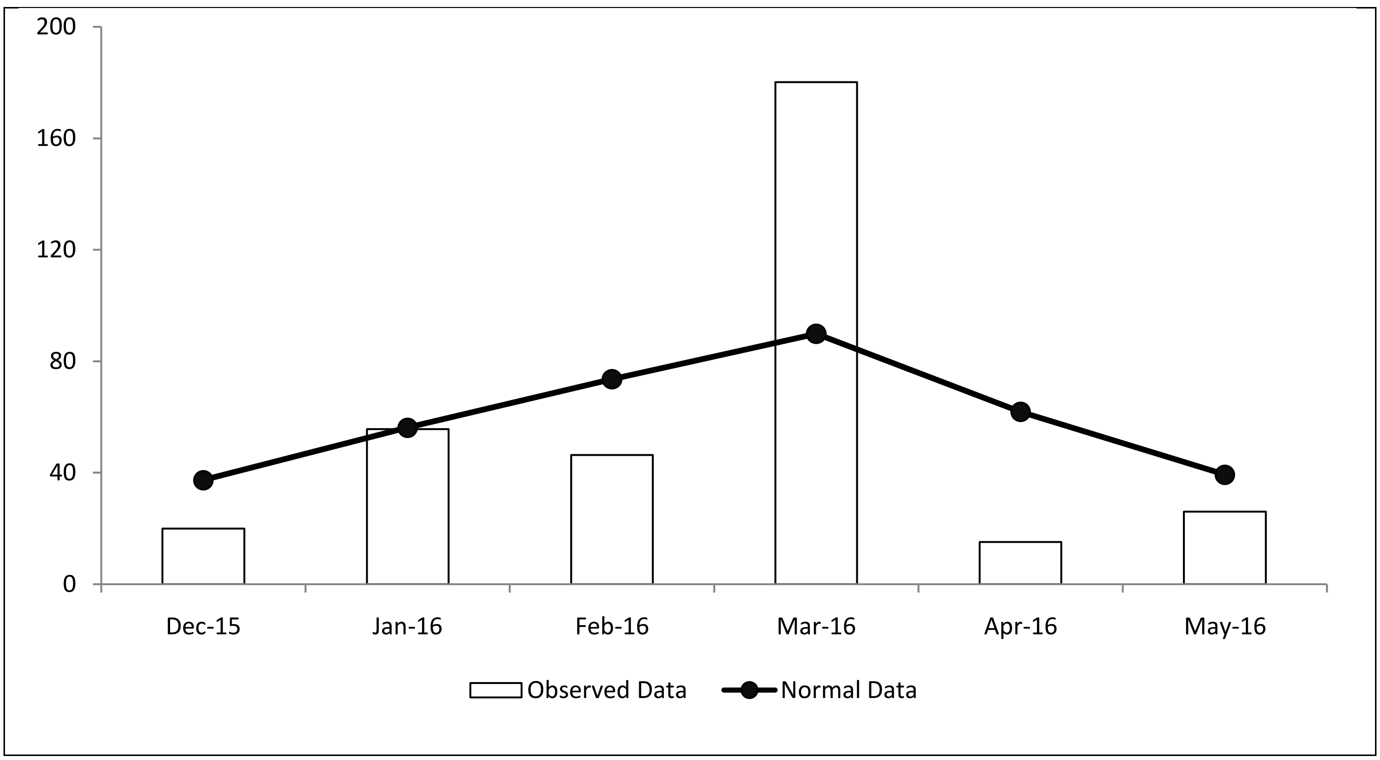

Figure 3.1: Comparison of Monthly observed rainfall with Normal (1981-2010) at Rawalpindi during Rabi Season (2015-16)

Table 3.2: Daily Rainfall History of the Crop Life 2015-16

Year	Phenological stage	Month	No. of Rainy Days	Rainfall (mm)	Monthly Total (mm)
2015	**Emergence**	**December**	**00**	**0.0**	**0.0**
2016	Emergence	January	00	0.0	
2016	Third leaf	January	01	41.0	
2016	Tillering	January	01	2.2	
2016	**Tillering**	**January**	**01**	**12.3**	**55.5**
2016	Shooting	February	01	34.3	
2016	**Heading**	**February**	**01**	**5.0**	**39.3**
2016	**Heading**	**March**	**12**	**180.1**	**180.1**
2016	Heading	April	03	2.8	
2016	**Flowering**	**April**	**05**	**12.3**	**15.1**
2016	Milk Maturity	May	01	1.2	
2016	Wax Maturity	May	03	7.4	
2016	**Full Maturity**	**May**	**00**	**0.0**	**8.6**

3.2 Air Temperature and Wheat 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 wheat crop it ranges between 0°C and 5°C.
- Optimum Temperature: at which maximum plant growth occurs. For wheat crop its value is 25°C.
- Maximum Temperature: above which the plant growth stops. For wheat crop its value is 30-32°C. [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).

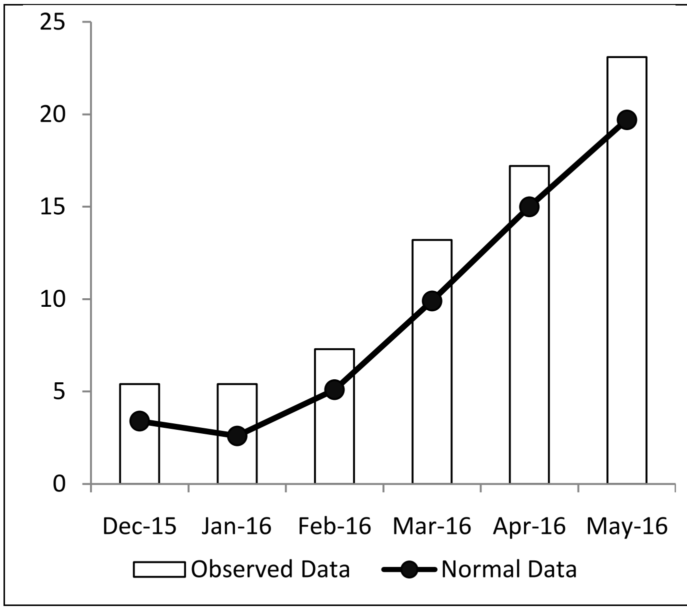

Figure 3.2: Mean daily Minimum Temperature (ºC) of Rawalpindi during the Rabi Season

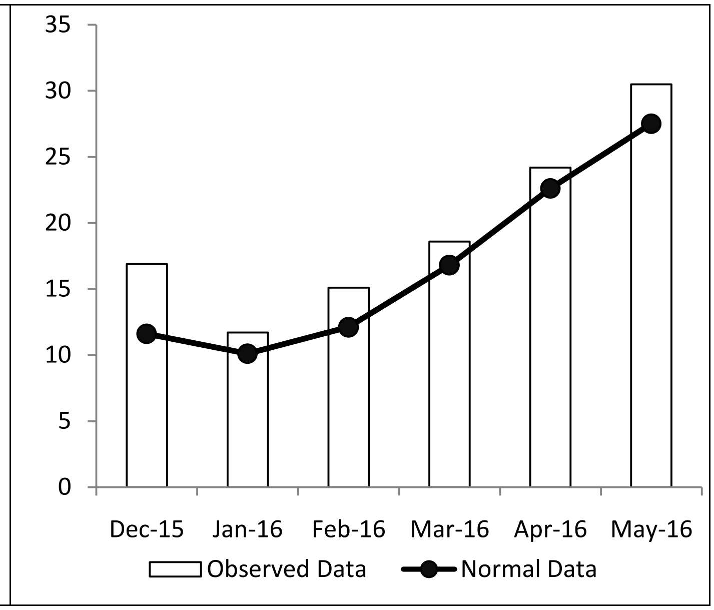

Figure 3.3: Mean daily Maximum Temperature (ºC) of Rawalpindi during the Rabi Season

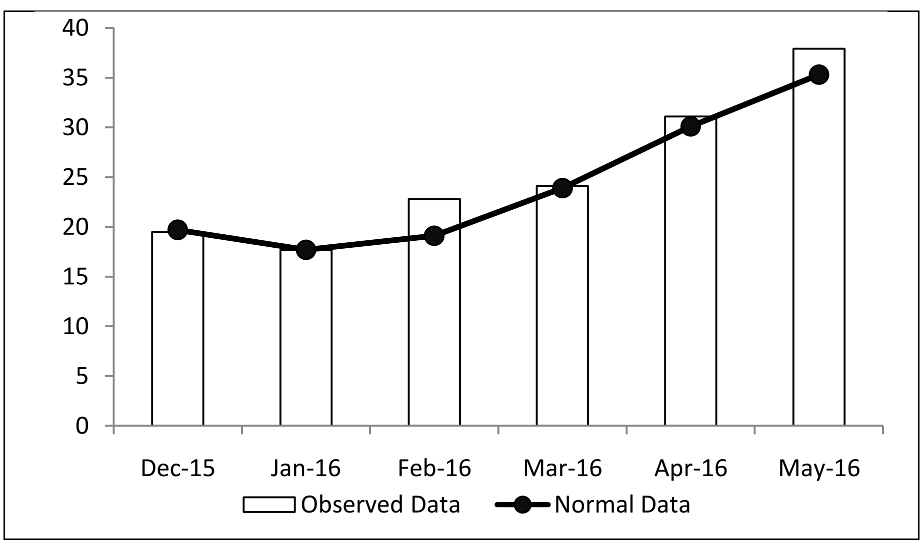

Figure 3.4: Mean Monthly Temperature of Rawalpindi during 2015-16

During the crop season of 2015–16, mean daily and day time maximum temperature remained mostly normal to below normal throughout the crop life cycle which favored satisfactory crop growth.

Table 3.3: Mean Monthly Temperature during Rabi Season 2015-16

Month	Mean Monthly (°C)	Monthly Mean Max.(°C)	Monthly Mean Min (°C)	Absolute Max. (°C)	Absolute Min. (°C)
Dec-2015	12.46 (11.6)	19.5 (19.7)	5.4 (3.4)	24.0 (26.2)	2.0 (-1.0)
Jan-2016	11.7 (10.1)	17.7 (17.7)	5.4 (2.6)	21.0 (26.1)	2.0 (-4.0)
Feb-2016	15.1 (12.1)	22.8 (19.1)	7.3 (5.1)	31.5 (30.0)	4.5 (-2.0)
Mar-2016	18.6 (16.9)	24.1 (23.9)	13.2 (9.9)	31.0 (34.0)	9.5 (-0.3)
April-2016	24.2 (22.6)	31.1 (30.1)	17.2 (15.0)	38.0 (40.6)	14.5 (6.1)
May-2016	30.5 (27.5)	37.9 (35.3)	23.1 (19.7)	42.5 (45.6)	19.4 (11.0)
*** ( ) in Table 3.3 shows Normal values (1981-2010)**					

3.3 Soil Moisture Observations during Crop Growth

Soil moisture plays a vital role during crop's life. Soil moisture content is proportional to rainfall and is inversely proportional to evapotranspiration from the plant and its surroundings. Variation in soil moisture during crop's life play important role in plant growth and development. Water or soil moisture requirement of wheat crop varies during different growth or Phenological stages. Highest amount is needed during flowering stage followed by grain formation stages and then vegetative stages [11].

To calculate soil moisture, soil samples are taken on 10^{th}, 20^{th} and 30^{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 2015–16, from the observed soil moisture data, figures (3.7 – 3.11) depicts that soil moisture remained satisfactory during early stages of the crop life whereas it remained slightly deficit in deep layers during intermediate stages (February & March) due to seasonal rise in direct solar radiation. During the maturity stages of the crop life, moisture conditions were satisfactory in deep soils as compared to ground level. But due to below normal crop water requirement (figure 3.11) rainfall reported during the crop life also fulfilled soil moisture requirement.

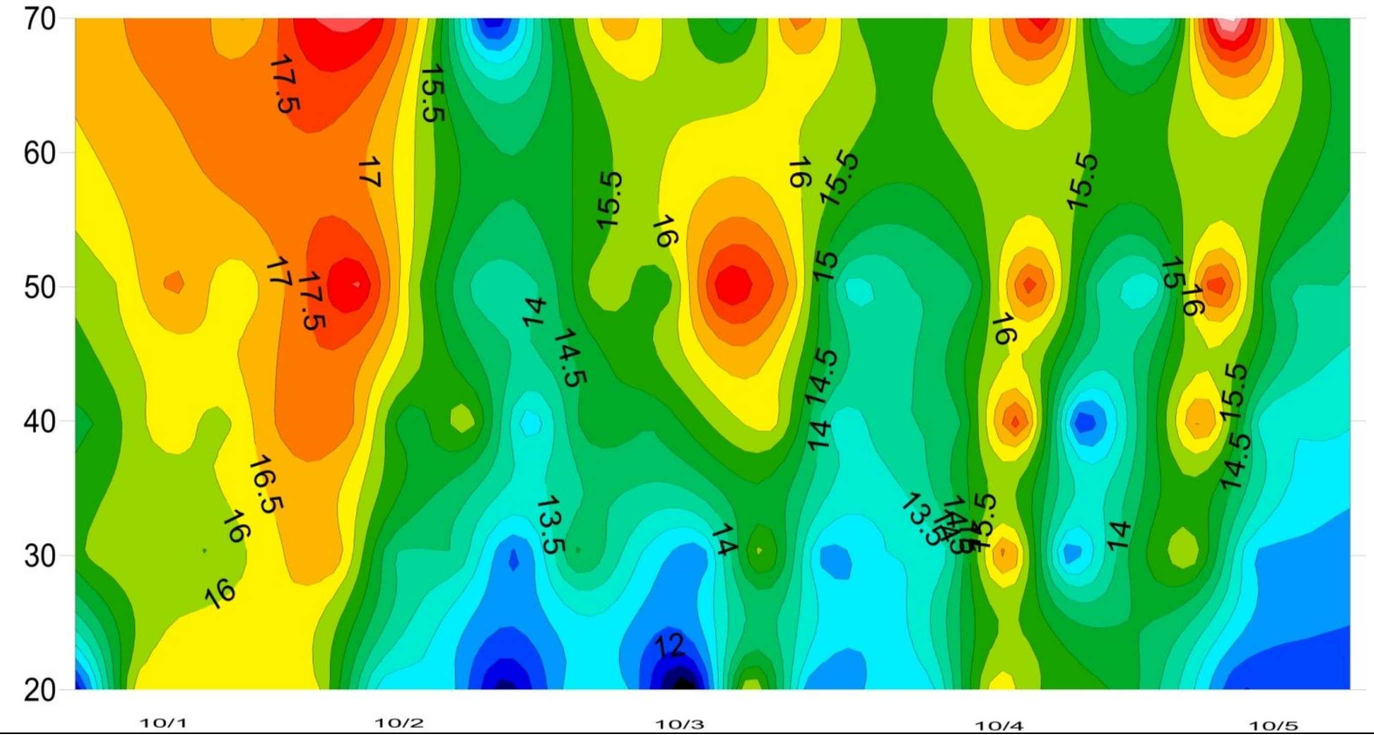

Figure 3.5: Soil moisture chrono Isopleths for Rabi Crop at Rawalpindi for the year 2015-16

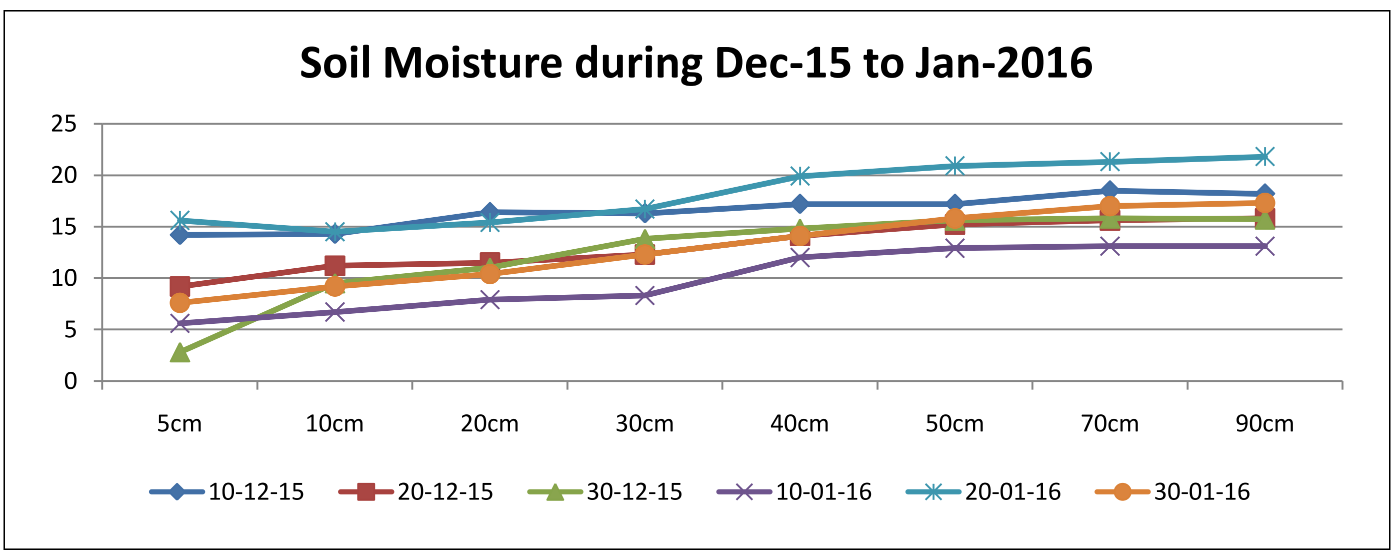

Figure 3.6: Soil Moisture during Dec-2015 to Jan-2016

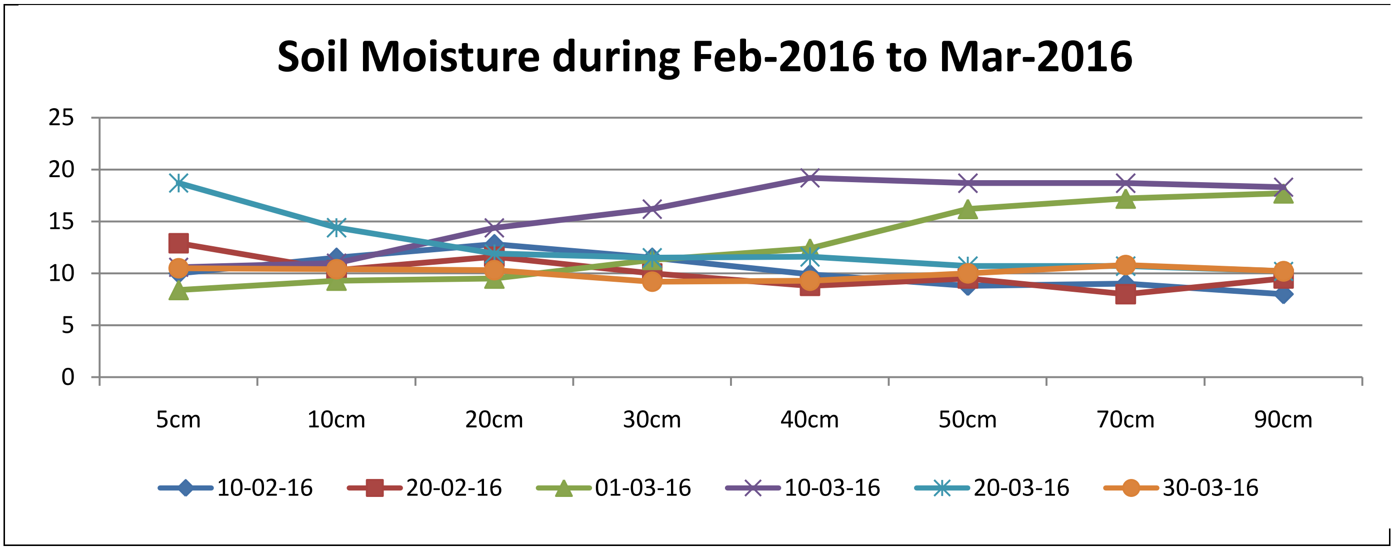

Figure 3.7: Soil Moisture during Feb-2016 to Mar-2016

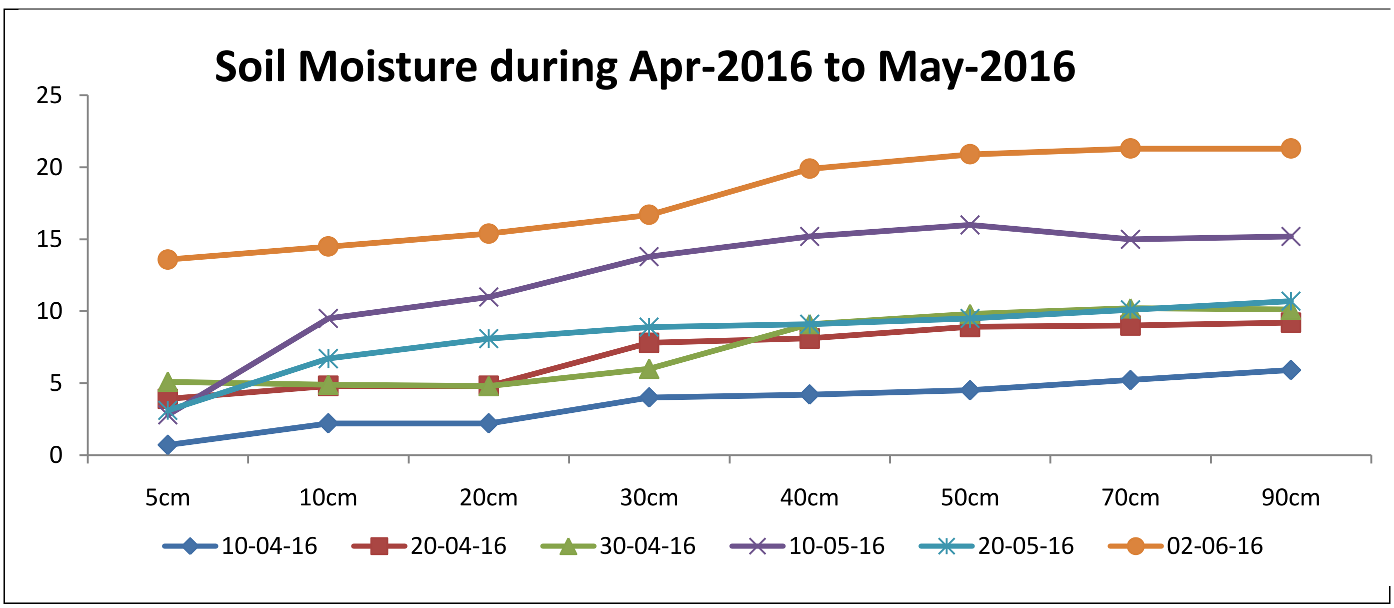

Figure 3.8: Soil Moisture during Apr-2016 to June-2016

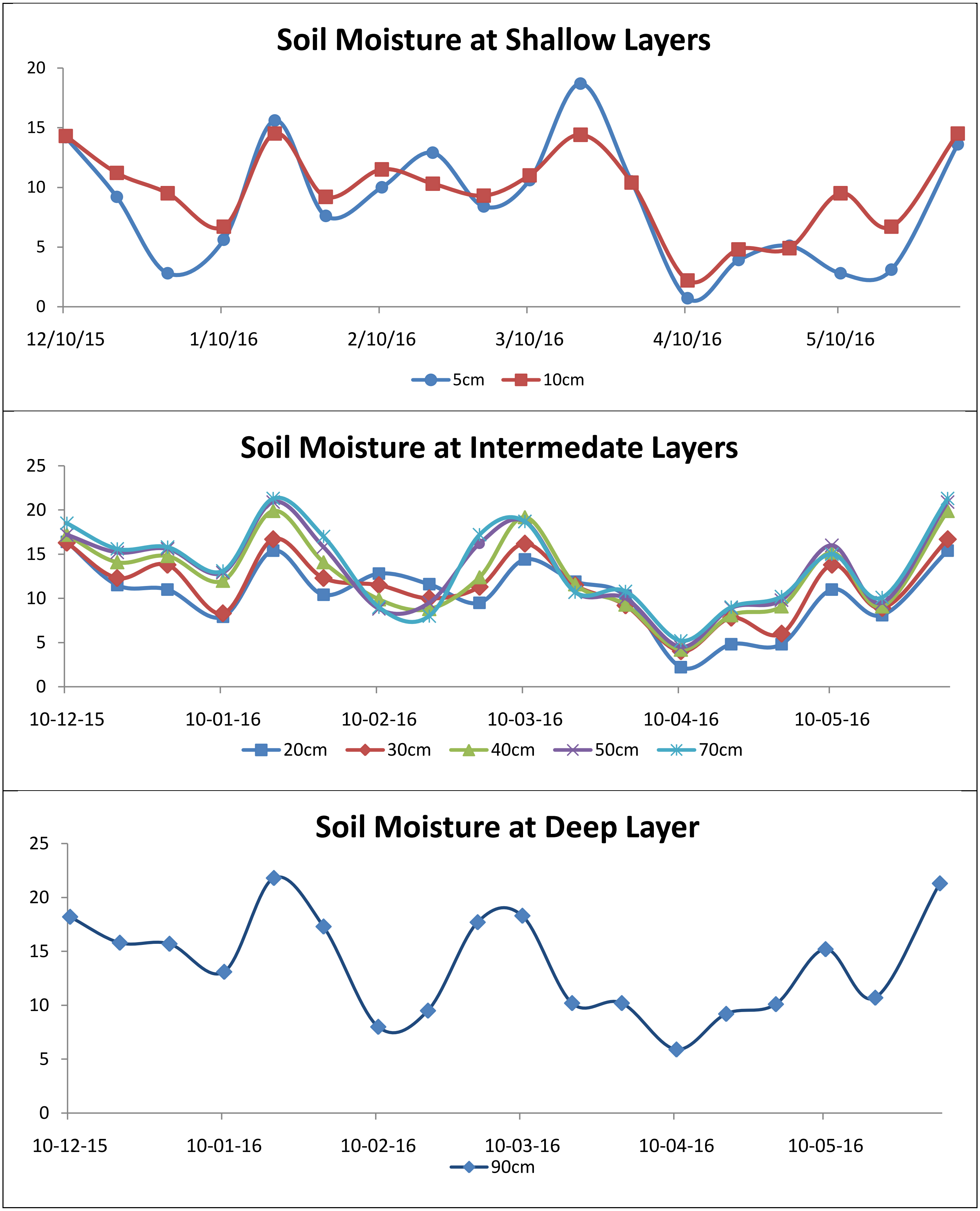

Figure 3.9: Soil Moisture at Shallow, Intermediate and Deep Layers

3.4 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 growth of wheat plant roots during the vegetative stage is below 20°C and is further lower than that for the shoots. [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 30 cm to 40 cm.

Note: This soil temperature data is collected from the soil observations taken at Agromet observatory of RAMC Rawalpindi situated near the experimental field of Arid Agriculture University Rawalpindi. 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 2015-16, soil temperature remained normal to above normal at all depths during most of the crop life, which favored satisfactory crop growth.

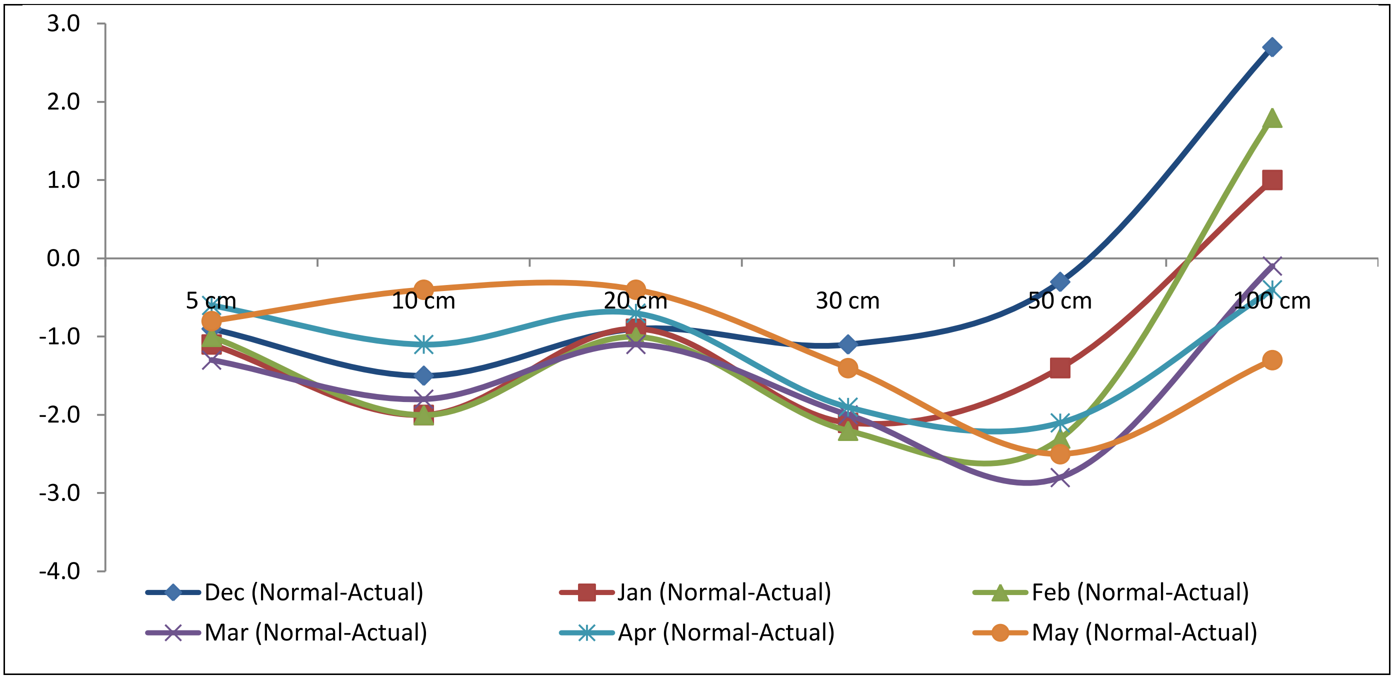

Figure 3.10: Soil Temperature During Wheat Crop 2015-16

3.5 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 wheat crop base temperature is 5°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].

Inter Phase period for wheat crop during 2015-16 and corresponding heat units at RAMC Rawalpindi 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 3.11 and table 3.4. Total heat units consumed by the wheat crop were 2270 accumulated from germination to full maturity in 159 days. On average 14.2 heat units were consumed by the crop per day. Normally these heat units are consumed in 140 days at the rate of 10.6 heat units per day, which shows that the crop reached to full maturity almost in normal thermal time. From figure 3.11 it is clear that crop consumed normal to below normal heat units from emergence to shooting phase, above normal heat units during heading to maturity phases were consumed so that these phases completed earlier than normal time.

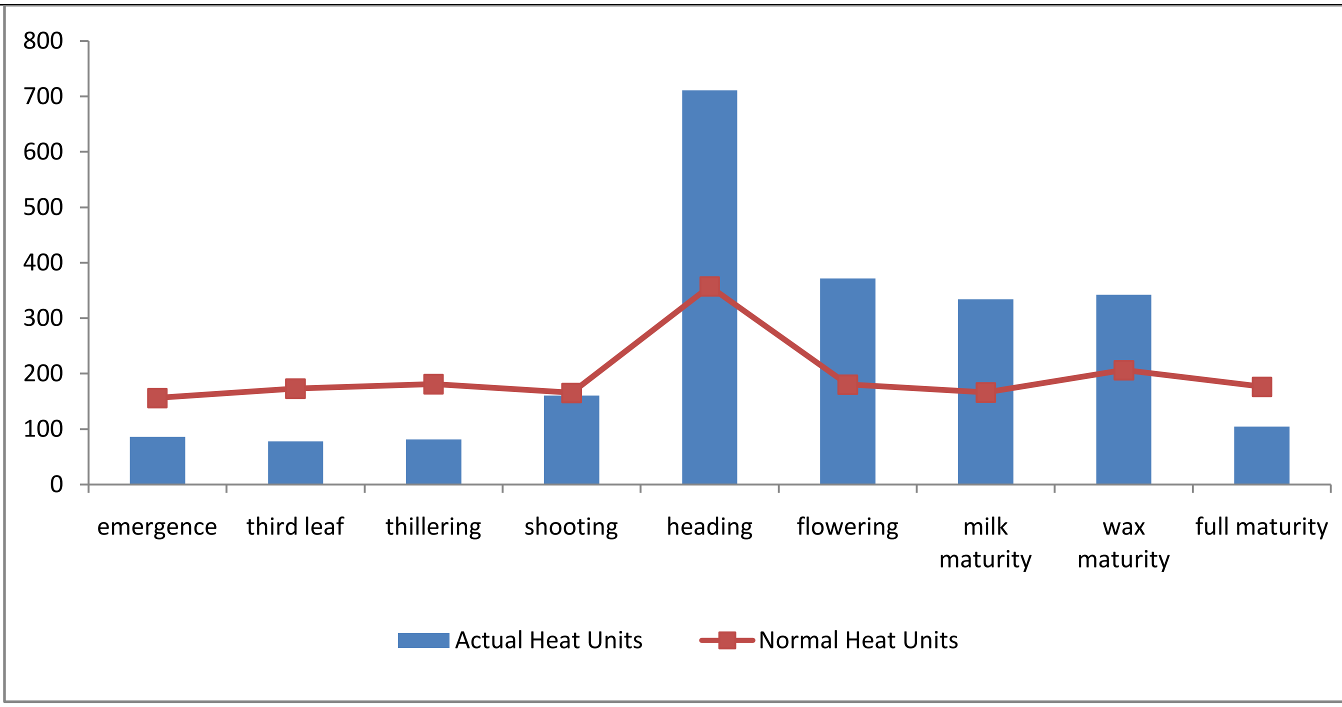

Figure 3.11: Heat Units During Crop Life 2015-16

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

S. No.	Interphase	Period	No. of Days Taken	Degree Days (T-5°C)	Normal Degree Days
1.	Emergence	22.12.2015 To 03.01.2016	13	86.6	156.6
2.	Third Leaf	04.01.2016 To 14.01.2016	11	78.2	173.4
3.	Tillering	15.01.2016 To 28.01.2016	14	81.5	181.0
4.	Shooting	29.01.2016 To 17.02.2016	20	160.7	165.0
5.	Heading	18.02.2016 To 08.04.2016	51	711.4	357.2
6.	Flowering	09.04.2016 To 27.04.2016	19	372.3	180.5
7.	Milk Maturity	28.04.2016 To 11.05.2016	14	334.4	166.6
8.	Wax Maturity	12.05.2016 To 24.05.2016	13	342.6	206.5
9.	Full Maturity	25.05.2016 To 28.05.2016	04	104.6	176.0
10.	**Emergence to Maturity**	**22.12.2015 To 28.05.2016**	**159**	**2270**	**1762.8**

3.6 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.

The range of RH during the crop cycle is from 34% to 63%. Maximum amount of RH is during tillering phase fallowed by third leaf, while minimum of RH is during maturity stages.

3.7 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 2015-16, relative humidity remained normal, whereas, ETo remained normal to below normal during most of the growing period. Below normal ETo during 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.

3.8 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. [12]

During the Rabi **crop period 2015-16**, no such bad weather event was observed. Wind speed was observed mostly normal and any significant wind speed accompanied by any severe weather event was not observed throughout this period.

Table 3.5: Summary of some Meteorological Parameters during Rabi Season 2015-16

Month	Wind speed (km/hr)	RH(%)	Days with mean RH ≥80%	ETo (mm/day)	Solar Radiation $Mj/M^2/day$
Dec-15	0.7	67.0	01	1.1	9.02
Jan-16	1.0	72.5	08	1.6	12.6
Feb-16	2.2	57.3	01	3.1	6.1
Mar-16	3.0	62.1	04	3.9	16.8
Apr-16	4.1	45.6	00	5.8	19.8
May-16	3.3	38.4	00	6.4	21.8

3.9 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:
- 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 wheat 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 [13].

3.9.1 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)

$$ETcrop = Kc. ETo \quad \text{or} \quad CWR = Kc. ETo$$

Crop coefficient (Kc) is actually the ratio of maximum crop evapotranspiration to reference crop evapotranspiration. For wheat, this ratio becomes 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 wax maturity. After wax ripeness practically there is no need of irrigation because the hot and dry conditions are desirable to achieve rapid hard maturity. A schematic variation of the crop coefficient related to different crop development stages under normal conditions is given in figure 3.10.

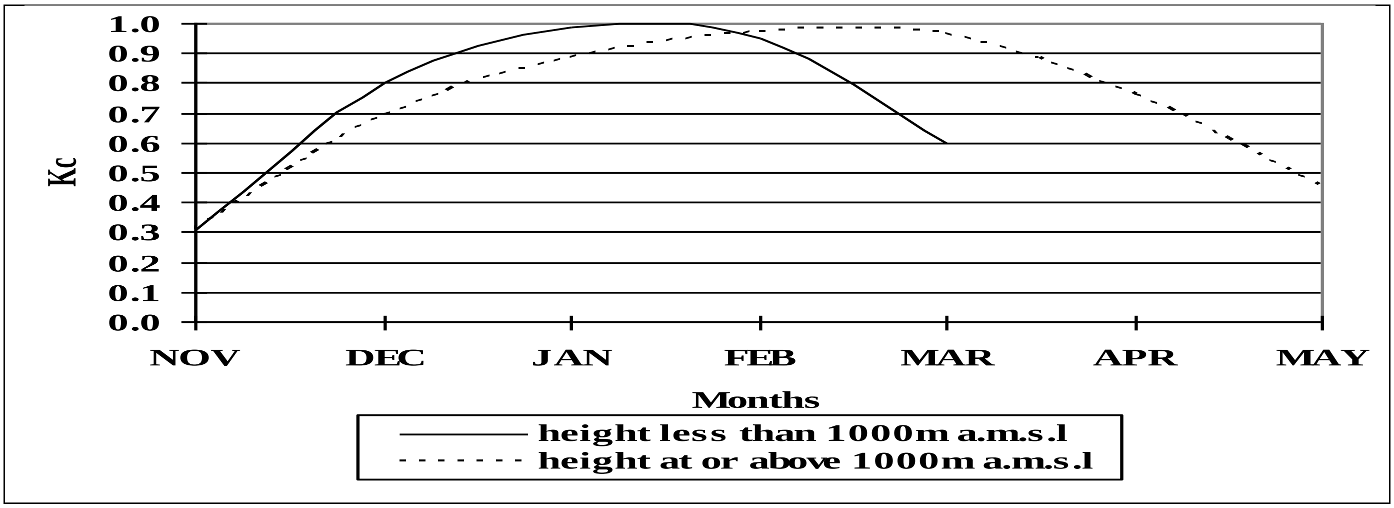

Figure 3.10: Graph of Crop Coefficient (Kc) for normal duration of Wheat growing season (Emergence to Wax Maturity)

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 [13].

During the **Rabi Season 2015-16** in Rawalpindi, crop water requirement of wheat crop was observed normal to below normal throughout the crop growth (Figure 3.11). It means that crop growth did not suffer in any phase due to sharp rise in crop water demand. Thus the available irrigated and rain water fully satisfied moisture requirement of the crop, which resulted normal crop growth.

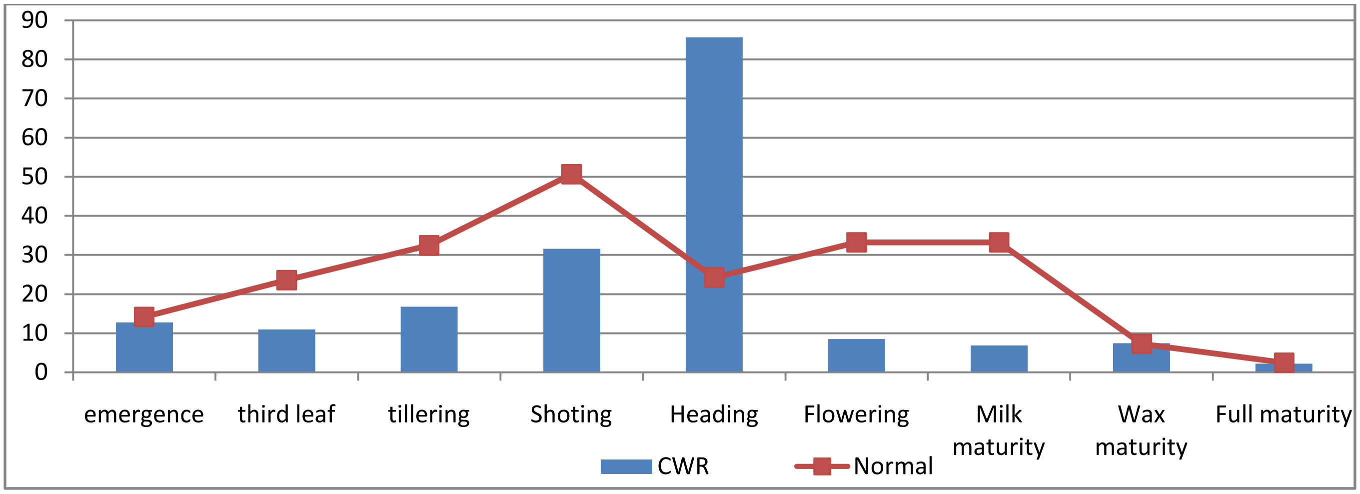

Figure 3.11: Crop Water Requirement (CWR) during crop life

Table 3.6: Heat 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	22.12.2015 To 03.01.2016	13	13	36.0	12.74	14.1
2.	Third Leaf	04.01.2016 To 14.01.2016	11	11	33.6	11	23.5
3.	Tillering	15.01.2016 To 28.01.2016	14	16.8	62.8	16.8	32.4
4.	Shooting	29.01.2016 To 17.02.2016	20	34	42.5	31.62	50.6
5.	Heading	18.02.2016 To 08.04.2016	51	142.8	110.1	85.68	24.2
6.	Flowering	09.04.2016 To 27.04.2016	19	85.5	52.8	8.55	33.2
7.	Milk Maturity	28.04.2016 To 11.05.2016	14	68.6	42.0	6.86	33.2
8.	Wax Maturity	12.05.2016 To 24.05.2016	13	74.1	61.0	7.41	7.2
9.	Full Maturity	25.05.2016 To 28.05.2016	04	22	49.0	2.2	2.4
10.	**Emergence to Maturity**	**22.12.2015 To 28.05.2016**	**159**	**467.8**	**489.8**	**182.86**	**220.8**

* Normals based upon 1991-2010 data

3.10 Agro Meteorological Summary of Crop Cycle

Different meteorological parameters were recorded at various phases of wheat crop during 2015-16. The impact of these parameters at different phenological stages of wheat crop is discussed as under.

3.10.1 Sowing

Wheat crop was sown on 12-12-2015. Due to non-availability of soil moisture, as Rawalpindi is rainfed region the crop was sown slightly late. Daily temperature was observed mostly normal and 20 mm amount of rainfall was recorded before sowing which provided the required moisture conditions for sowing.

3.10.2 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 64%. Mean air temperature during emergence was 11°C. Rainfall was not received at this stage and 86.6 units of heat were consumed to complete, which are far less than the normal heat units .So, the stage took more time to complete than normal..

3.10.3 Third Leaf

The mean relative humidity during this phenological stage was 72% and mean air temperature was 12°C. This stage received 41.6 mm amount of rainfall for a day. As the mean air temperature was greater than normal during this stage therefore crop took less more to complete its phase.

3.10.4 Tillering

The mean air temperature during this phenological stage was 11°C and mean relative humidity was around 74%. This stage received 2.2 mm amount of rainfall for a day.

3.10.5 Shooting

During this phase stem extension occurred in the crop. The mean air temperature was 13°C and mean relative humidity was 63% during this stage. Fertilizer was added to the crop. A rain spell of about 53.6 mm for 02 days was experience during this stage which did not affected the crop and its further growth. and the crop consumed normal heat units and completed on time.

3.10.6 Heading

It is the initiation of reproductive stage of wheat crop. The mean air temperature was 19°C during the heading phase. The relative humidity was around 59%. A heavy spell of rainfall 187.9 mm in 16 days was experienced which favored the development of standing crop. and pest attack was found. this stage completed earlier than normal and consumed 711 heat units which are very high than normal.

3.10.7 Flowering

The mean air temperature during this stage was recorded as 25°C and mean relative humidity around 43%. Fertilizer was added to the crop. This stage received 12.3 mm rainfall in 05 days.

3.10.8 Milk Maturity

Seed formation is considered as the most important phenological stage of the plant growth. The mean air temperature was recorded as 29°C whereas mean relative humidity during this phase was 39%. This stage experienced 1.2 mm amount of rain in a day. During this stage amount of rainfall supported the development of crop.

3.10.9 Wax Maturity

The mean air temperature was 31°C and relative humidity was recorded as 37% during wax maturity phase. The temperature range from normal to below normal during this stage. This phase experienced 7.4 mm rainfall for 03 days.

3.10.10 Full Maturity

Wheat requires high temperature at this stage for maturity. The mean air temperature recorded during this phase was 31°C and the relative humidity was 37%. This stage experienced no rainfall, which favoured the standing crop growth at this stage.

Chapter 4

CONCLUSION AND RECOMMENDATIONS

The crop variety Chakwal 97 was cultivated in the experimental field of University of Arid Agriculture Rawalpindi. The sowing time of wheat is a very important factor. The time of sowing of wheat is directly related to yield and quality of grain produced.

According to Table – 3.1 and Chapter-3 (Results and Discussion), the crop was sown slightly late. Amount of seed cultivated per acre was 50 kg which is sufficient for the crop cultivated in December. Fertilizer intake was also enough i.e., 1 DAP bag/acre and ½ Urea half bag/Acre at the time of sowing and 1 bag Urea at shooting and flowering stages respectively were added to the crop. Rainfall received amounting 20.0 mm was reported for a day in December, 55.7 mm for 04 days in January during early to mid growing stages. In the month of February, below normal rainfall amounting 46.3 mm was reported for 03 days during shooting/heading stages. In March above normal heavy rainfall amounting 180.1 mm for 12 days was reported during heading stage. During April rainfall amounting 15.1 mm for 08 days reported from heading to milk maturity stages. Whereas rainfall amounting 26.0 mm for 05 days was recorded in May from milk maturity to full maturity stages. Day and night time temperatures also observed in normal range. RH was observed to be approximately normal throughout the crop life. 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. No serious moisture stress was observed during the crop growth. Total heat units consumed by the wheat crop were 2270 accumulated from germination to full maturity in 159 days. On average 14.2 heat units were consumed by the crop per day, which shows that the crop reached to full maturity in above normal thermal time. From figure 3.11 it is clear that crop consumed normal to below normal heat units during the early stages of crop growth whereas from heading to maturity stages slightly 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 2015-16 recommended weedicides operations were performed in time, which also reinforced crop's growth and production.

4.1 Conclusions

During the Rabi season 2015-16, most of the air and soil weather parameters like air and soil temperature, crop water requirement remained normal to below normal during the crop growth from sowing to flowering stages, which favored normal crop growth. Normal amount of seed was sown and normal doze of fertilizer was added to the crop. Amount and frequency of rainfall was in favor of crop during shooting and maturity stages which positively promoted the crop growth. However rainfall in April and May during very crucial crop growing stages from milk maturity to full maturity affected the standing crop which resulted in 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 wheat crop yield in central Punjab as well as all over Pakistan.

1 – Farmers generally plant wheat late in rice-wheat, sugarcane-wheat, and cotton-wheat areas due to late harvesting of Kharif crop which results in drastic low yields because the crop is exposed to heat stress at grain formation stages (milk and wax maturity stages) leading to the formation of shriveled grain. Late-planted crop has lower germination, fewer tillers, smaller heads, shriveled grain and lower biomass than the timely planted crop. Any delay in planting would reduce yield drastically. To achieve good yield, sowing of wheat should be completed up to the mid of November in the irrigated planes of Punjab.

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

3 – Diseases, especially rusts (Stripe/Yellow Rust, Stem Rust, and Leaf Rust) and emerging scenario of increased incidences of Powdery Mildew and aphid are major biotic stresses of wheat crop that inflict heavy losses when in epidemic form. A simple one-year disease epidemic could cause a 2-3 billion-rupees loss to the country because of reduction in wheat yield (an example of 1977-78 epidemics). Therefore, breeders and pathologists should join hands to develop disease resistant and high yielding varieties in order to cope with threats created by ever changing rust races by using approaches like durable resistance. Farmers should use approved verities of pesticides and insecticides.

4 – The frequency of extreme weather events like heat waves, cold waves, flash flooding, and heavy snowfall has increased globally including Pakistan in the last decade due to climate change. Pakistan has also been 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 wheat production both in irrigated and rainfed areas. 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. Researches should also keep focus on to update sowing dates due to late arrival of winter season and winter rainfall in most of the agricultural plains of Pakistan. Keeping in mind the available water resources, it is also indeed necessary to decide suitable crops 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 get best results of fertilizer and irrigated water used.

6 – Weeds being the main robbers of plant food from soil; space and even light required for wheat 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.

7 – Seed of high yielding wheat 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.

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

9 – Care must be taken to check the pre and post-harvest losses of wheat. Pre-harvest damage may be checked from attack of birds, animals around wheat fields. Post-harvest losses must be checked from the attack of rodents and other insects, pests and fungi. After proper trashing, wheat grains should be placed under hygienic conditions in fields and in storage places as well. Uses of powdered neem leaves in the bags of wheat grains will also seemed to be useful, which is a traditional treatment for preservation of cereal grains.

10 – Crop rotation is an important factor that enriches the fertility of the land, which should not be ignored. Pulses are preferred as they enrich the nitrogen content of soil for the coming wheat crop.

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