Early Yield Assessment of Wheat on Meteorological Basis for Potohar Region

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Abstract

The farmers of rainfed areas get low yields as rich as compared to the ones from the irrigated land, due to several natural constraints among which water availability is the major one. It is considered reasonable that yield forecast should be made as early as possible before harvesting. For rainfed areas yield assessment (of wheat crop) can be made based on Tillering to reproductive stage in late February or early March. Although the growth of any crop is not only dependant on weather parameters yet they have a great impact on final yield produced. This study revealed that at a particular time some meteorological parameters act as the main actor for the physical growth of wheat crop and the final yield in the end. During the 1st & 2nd decade of January, the moderate amount of rainfall (up to 40 mm) is favourable for a better yield. Heavy rains at this stage may have adverse effects on the final yield. Throughout the wheat grown season, if rainfall exceeds 120 mm then the final yield obtained may be good or above average. Reproductive stage (heading to grain formation) is the most critical period in the life cycle of wheat crop. A slight shortfall or excess of water produces drastic changes in the economic yield of the crop. Heat units during the early age and particularly at the beginning of reproductive stage should be equal to or slightly above than the normal to get optimum yield. Mean minimum temperature should be higher during first two decades of January and lower in the 2nd decade of February to harvest good economic yield. Higher than normal temperatures in February shorten the period for reproduction. Less number of grains per spike, smaller size and weight of grain are the outcome. During the 3rd decade of January & 1st decade of March higher duration of bright sunshine is favourable for a better yield.

Keywords: Rainfed areas, Potohar region, Yield forecast, weather parameters

Introduction

Pakistan Agricultural Research Council has distributed Pakistan into ten agro-ecological regions on the bases of physiography, geology, climate, agricultural land use and water availability. The agro-ecological zone-V (Rainfed areas) covers the Potohar plateau, Salt Range, and Himalayan Piedmont plains. The soils of the Rainfed areas are classified as silt loam, silty clay loam, and clay loam. Areas that are always moist or warm are not suitable for wheat crop. Well drained clay loams, loams and sandy loams are the best soils for wheat. Wheat is commonly sown normally October to November under rainfed conditions and around the middle of November under irrigated conditions. The Potohar plateau is bounded in the north by the Kala-Chitta and the Margalla ranges, in the east by the Jehlum River, in the south by the Salt range and in the west by the Indus River. (PARC, 1980).

Wheat is an important cereal and cash crop for any country especially for an agricultural-developing state like Pakistan. Pakistan is one of the major wheat producers of the world (Dowswell, 1989). It is essentially better from nutritional point of view than most cereals and other food staples. In Pakistan, spring wheat is grown as a Rabi crop in the Sindh, Punjab, NWFP, and Baluchistan provinces. In the northern parts of Baluchistan, some winter wheat is cultivated on a small scale It is grown on an area of about 8.5 million hectares in Pakistan and nearly 70 % of this area is irrigated, which constitutes about 36 % of the total irrigated area in the country while 30 % is northern rain fed. Rainfed areas are concentrated in Potohar plateau, northern mountains, and northeastern plains of the country forming the largest contiguous block of dry land farming in Pakistan (GoP, 2006).

The Potohar area has great agricultural potential to lower down the import load of the country (Ijaz and Ahmad, 2006).The land resources of Potohar are characterized with fragmented land holdings. The agricultural activities in these areas contribute about 10 percent of total agricultural production. In the context of crop production, barani lands have often been underestimated, however, more than 1200

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kg/acre of wheat have reportedly been produced in this area, which reveals a high potential for crop production (Ashraf, 2004).

Since the beginning of agriculture, farmers have always been interested in assessing the size of their future harvest in the relation to what they have sown (Rasul, 1993). With the passage of time food crises has grown severely throughout the globe especially in the developing countries like ours. Consequently, it has become increasingly necessary to forecast the size and quality of harvests, particularly for cereal crops, which remain the best source of food in most parts of the world. Forecasts are very important to help the wheat producing countries to know in advance the size of the harvest and the portion of which can be exported or how much would be imported (FAO 73, 1986).

Climatically Potohar plateau lies in the semi-arid region, influenced mainly by summer monsoon (July-September) and partly from winter precipitation as well. Early rains during winter are beneficial for timely sowing of wheat crop in Potohar region. Also the early spring rains results into healthier final growth and better yield of wheat crop in the area. (Rasul, 1993).

Higher rainfall variance seems to the main factor behind dry-land yield fluctuations. Amount and distribution of Rainfall during crop season are important. Distribution of rainfall becomes more significant for the lands with low water holding capability and also in the seasons with adequate soil moisture available at planting (Pratley, 2003).

Increasing temperatures may have a positive impact on agriculture in the mountain areas, for instance through shortening of growing period for the winter season crops. Winter crops (e.g. wheat) in the high mountain areas, do not even reach to maturity in most cases and as such the crop is harvested premature and used as fodder. The shortening of the growing season length due to rising temperature could be beneficial in the mountain areas as it would help the winter crops in timely maturity and as such would allow the crop to mature in the optimal period of time, with beneficial effects on crop area and yields (Hussain and Mudasser, 2004).

The interaction between meteorological parameters and crop's growth are more pronounced at some particular phenological stages. And it is weather not climate which may be used as an input for the purpose of yield prediction in crop modeling. Although the seasonal weather forecasting is a tough task but it may be the best input for a crop model. After establishing a relation between the seasonal weather pattern and final yield, a proper modeling track may be designed (Challinor et al, 2003).

There are a number of meteorological parameters considered significant for wheat crop, but some of them are found to be much more important during some particuler stages in crop life cycle. Also the farmers of arid or rainfed areas (like potohar) are more vulnerable to weather. Therefore, in this study it has been tried to established some relationship between weather elements and the crop, in order to estimate the final yield well before harvesting. For the purpose last 15 years real time meteorological data has been utilized. And the approach being employed is purely statistical.

Phenological Stages

Phonological stages are very important icons as they portray the on going condition of the growing crop. Wheat crop has mainly nine phonological stages (excluding germination).

On average the occurrence & duration of different phonological stages of wheat in Potohar is as under;

Table 1: Occurrence & duration for phonological stages of wheat in Potohar (Based upon 15 years phenological data collected at RAMC Rawalpindi).

Sr. No.	PHASE	PERIOD
1	EMERGENCE	15 NOV-30 NOV
2	THIRD LEAF	01 DEC-20 DEC
3	TILLERING	21 DEC-15 JAN
4	SHOOTING	16 JAN-25 FEB
5	HEADING	26 FEB-05 MAR
6	FLOWERING	06 MAR-20 MAR
7	MILK MATURITY	21 MAR-18 APR
8	WAX MATURITY	19 APR-25 APR
9	FULL MATURITY	26 APR-28 APR

Data Used and Methodology

Observed meteorological data recorded at RAMC (Regional Agromet Centre of PMD), Rawalpindi is used in this study. At an RAMC the meteorological data is recorded thrice a day i.e, 0800, 1400 & 1700 PST. Yield data recorded at NARC (National Agricultural Research Centre) and RAMC, Rawalpindi has been used in this study.

It is evident from the research conducted so far, that there are a number of meteorological/climatic factors which affect the growth and ultimately the final yield of the crops, like wheat. But among all these the importance of rain is more pronounced, rainfall occurring time, amount and also its intensity play a vital role in final yield obtained.

Besides rainfall other meteorological factors like minimum, maximum & mean temperature, wind speed, relative humidity, evapotranspiration and heating degree days or heat units are also considered important in early assessment of a crop's yield. Considering all the said facts, data of all these parameters is analyzed on decadal (10 days), phonological stage wise and on seasonal basis as well. The approach being used is mainly statistical, including applications like regression, correlation and mean deviation etc. Because of having a variety of data sets, each of the parameters is discussed separately with its overall impacts on wheat crop at different time/ stage. The average or normal values used for each parameter is based on the last 15 years data.

Some parameters like reference crop evapotranspiration (ETo) and heat units etc which cannot be measured directly and some specific methods are used for their calculation. 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 heat units or growing degree days for a particular crop on any day is the difference between the daily mean temperature (T) and the base temperature (Tb) of the crop. For example, the base temperature for wheat is 5°C, so on a day with mean temperature 10.5°C, the number of heat units will be 5.5. Starting from the early growth, the daily heat units are added. If 1800 heat units are needed for a crop (wheat) to mature then the crop should be ready for harvesting when the accumulation reaches 1800. The period of negative value is termed as "dormant" because no growth of crop takes place under such situation.

Calculation of Heat Units:

There are mainly two methods being used for calculation of heat units i.e. active method, in which directly mean temperature is added and effective method, in which the threshold temperature along with the mean temperature is used.

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

$$\sum\left(\overline{T}-T_b\right)=K \quad \text{if} \quad \overline{T}>T_b$$

&

$$\left(\overline{T}-T_b\right)=0 \quad \text{if} \quad \overline{T}<T_b$$

where

$\overline{T}$ = Mean daily temperature, T_b = Biological zero, K = Heat Units

Calculation of ETo:

There are a number of methods being used for ETo calculation but Blaney-Criddle is one for which very limited meteorological data is required. Also the method is suitable for stations at high latitudes and monsoon climates as well (FAO 24, 1992). This is being used in Pakistan over decades.

<u>Blaney-Criddle Method:</u>

This method is suggested for areas where available climatic data cover air temperature data only. The original Blaney Criddle equation (1950) involves the calculation of the consumptive use factor (f) from mean temperature (T) and percentage (p) of total annual daylight hours occurring during the period being considered.

The relationship recommended, representing mean value over the given month, is expressed as:

$$ETo = c\left[\,p\left(0.46T+8.13\right)\right]\ mm/day$$

where

ETo = reference crop evapotranspiration in mm/day for the month considered
T = mean daily temperature in °C over the month considered.
p = mean daily percentage of total annual day time hours obtained
c = adjustment factor, which depends on minimum relative humidity, sunshine hours and daytime wind estimates.

Results & Discussion

Significance of Rainfall

Rain has immense importance during the growth and development of wheat crop both in rainfed and irrigated conditions. In rainfed areas the crop is totally dependant upon rain from the land preparation to the time of maturity but in irrigated fields rain provides clean environmental conditions to support optimum photoperiodic activity for better biomass and grain yield. As every crop requires water for its life cycle to continue in an optimal manner, but in rainfed areas like Potohar the only source of water is rain. Therefore, its importance is more pronounced in these areas for a prominent cereal crop like wheat. Luckily, Potohar is situated in the track of summer monsoon currents from the east and also in winter westerly currents approach this region. As a result generally optimum rains occur throughout the year. In this area normally about 60% of the annual rain occurs during summer monsoon while about 40 % rain occurred during winter when wheat is grown (Chaudhry, 1991).

In rainfed areas, it is highly desirable that density of rain measuring network should be reasonable. Despite this known fact, the number of meteorological stations in rainfed area is few, developed a simple method for estimation of rainfall in areas where raingauges are not installed. This method proved to be much helpful for Potohar and Baluchistan plateau (Rasul, 2001). .Moisture through rain is main factor for a crop to grow in rainfed areas, therefore it is discussed & analyzed on decadal, phenological and seasonal basis to see how it affected the final yield obtained in different Rabi seasons during the last 15 years. Decadal rain and yield correlations may have good relationship for setting up prediction criteria.

Decadal Rainfall & Final Yield

This section covers the rainfall relation with the yield on decadal basis. Rainfall occurred during the first decade of November is analyzed (Fig.1.a) as it is normally the sowing decade for wheat in elevated agricultural plains of Potohar plateau. An optimum amount of precipitation results into good germination and supports well the initial establishment of the crop. It may have a positive impact on seedling growth, number of fertile tillers per plant and the final yield as well.

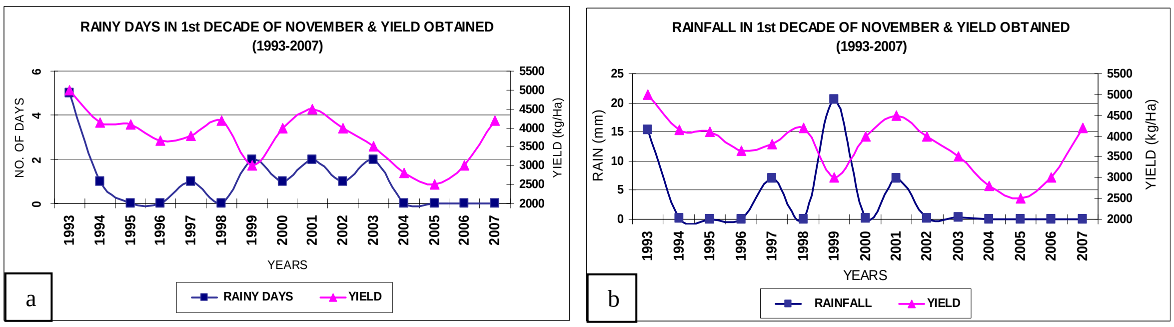


Fig. 1(a) Rainfall and **(b)** rainy days during 1st decade of November verses yield final during 1993-2007.

Unfortunately meteorological statistics shows that rain seldom occurred in this decade during the last fifteen years, if some time it occurred, a better yield had been produced except 1999 when yield dropped despite a good rain during that decade. Like rainfall, the rainy days in November remained very few, but their numbers impose a positive impact on the final yield.

As the months of January & February match the youth of wheat crop and are very critical for a Rabi crop like wheat, therefore, the rain during different decades of these two months along with rainy days has been analyzed relative to the final yield obtained. During February the rain has not shown any significant correlation with final yield so, only the significant decades of January are presented here.

The rainfall during 1st decade of January (Fig. 2.a) has generally a good relation to the final yield. It has been seen that during the last 15 years the rainfall up to 35 mm has good impact on the wheat yield. The regression has not indicated a rather good relation between rain & the final yield. The higher amount of rainfall than threshold caused yield reductions.

The rainfall occurred during 2nd decade of January has shown very good relation with the final yield obtained, in the last 15 years (Figure 2.b). It is very important result that if fewer rains occurred in the first two decades of January then we may expect good yield in the end. The reason seems to be related to the photosynthesis. Prevailing cloudiness hinders this activity and carbohydrates as well as dry matter production remains low which results in lower yields.

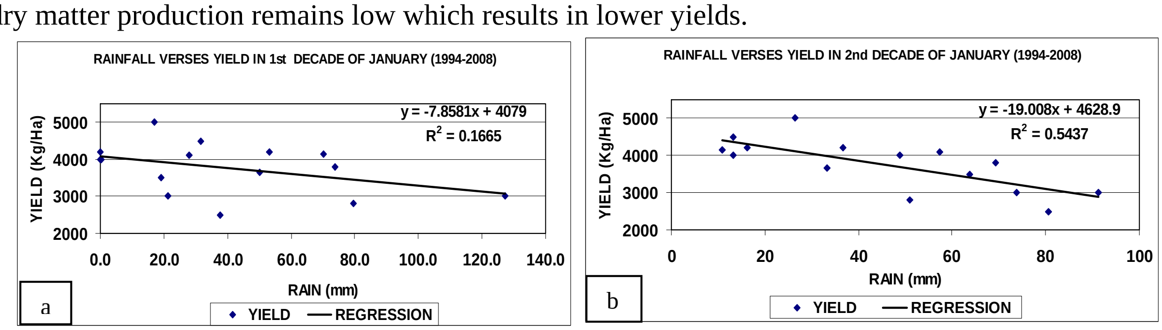


Fig 2 (a) Rainfall during 1st and **(b)** 2nd decade of January verses final yield during 1994-2008.

Critical Rainfall

In this section the rainfall patterns during October-March & January-February, in the last 15 years are discussed relative to the yield gain in the end.

It can be seen from the Figure 3.a, that when ever the rain occurred about 150 mm or more in the said period, the final yield harvested was good. In Figure 3.b, it is further indicated that why in some years with more rain low yield was obtained in the end.

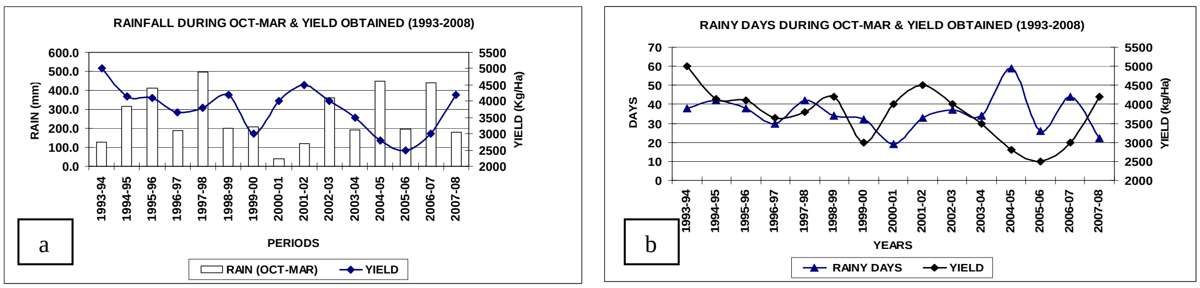


Fig 3 (a) Rainfall and **(b)** rainy days during Oct-Mar and final yield during 1993-2008.

Reproductive stage (heading to grain formation) is the most critical period in the life cycle of crops. A slight shortfall or excess of water produces drastic changes in the economic yield of the crop. The pattern of rainfall during the reproductive stage (Jan-Feb) is almost same as during October-March. Whenever rains occurred above 75 mm, the final yield produced was good. This is also shown in the Figure 4.b, in which 12 or more rainy days during January-February have resulted into a better yield in the end.

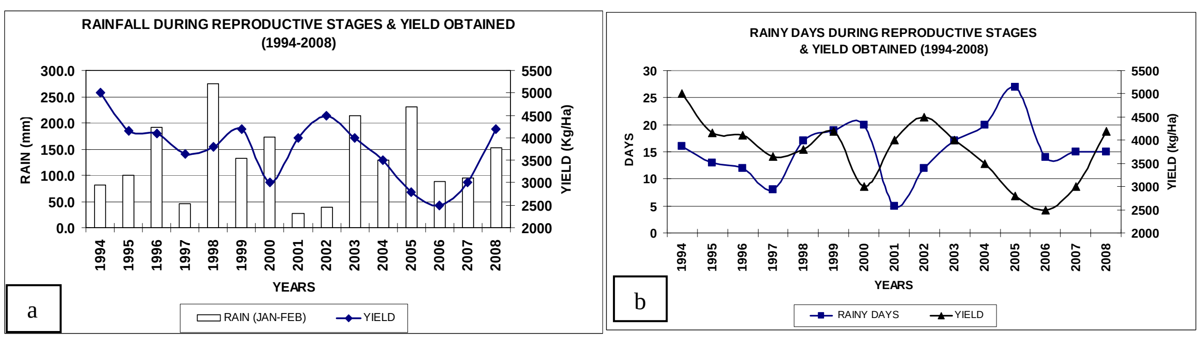


Fig 4.(a). Rainfall and **(b)** rainy days during Jan-Feb and final yield during 1994-2008.

Heat Units

As heat units or degree days are widely known as a practical application of temperature data which is used in agriculture to predict the approximate date for the crops to be ready for harvest. Heat units can be used relative to different phonological phases to go for early assessment of the final yield of wheat.

First of all accumulated heat units have been analyzed for Rabi seasons with variable yield production. The purpose was to investigate the heat units behaviour at different phenological stages and the yield response in consequence. Sum of heat units is taken from first phase set in date to next phase set in date. The phase is said to be set in when 10 % plants show that phase. Inter phase sum of heat units differ from phase to phase in accordance with time taken.

It can be seen from the fig 5.a, that heat units (H.U) during Rabi 1993-94 were ahead of the normal values right from the beginning of the emergence stage. The actual curve came closer to the normal during reproductive stages (heading to grain formation) and also in the last two stages. The normal values for H.U. in the stages tillering, shooting & heading are 571, 742 & 959 respectively but in this season the actual values remained 626, 821 & 993 respectively. The warming at the reproductive stage accelerate the growth of the plant, consequently less time is available for the grain to gain size and weight. The increased values at these stages may produce some bad effects. However, during this particular year environment returned to normal and best yield was harvested i.e. 5000 Kg/Ha.

During Rabi 2002-03 (Fig 5.b), also the actual heat units remained mostly higher than or equivalent to the normal. The normal values for H.U. in the stages tillering, shooting & heading are 571, 742 & 959 respectively but in this year the actual values remain 607, 795 & 998 respectively. The increased values at these stages may affect negatively but in the final stages of the crop it came closer to the normal conditions and a better yield produced of 4000 Kg/Ha in the year 2002-03. If we compare final stages of wax & full maturity of wheat during Rabi 2002-03 with Rabi 1993-94 (the best season for yield production in last 15 years), it can be seen that the actual H.U. in Rabi 2002-03 were higher than the normal values. While in Rabi 1993-94 actual & normal H.U were almost same. This might have been the reason for 1000 Kg/Ha reduction in wheat yield during Rabi 2002-2003 from the best yield season.

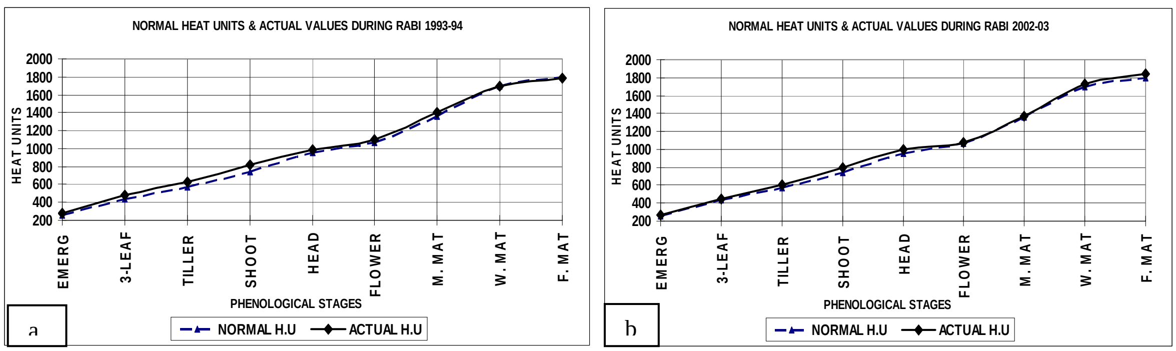


Fig 5 (a).Normal and observed heat units for wheat crop during Rabi 1993-94 and **(b)** Rabi 2002-03.

During Rabi 2003-04 (Fig. 6.a), the H.U. were closer to normal in the initial stages but as the crop entered into the reproductive mode, it abruptly increased and became 200 units ahead of normal in the last stage. This might be the main reason for low yield during Rabi 2003-04, i.e. 3500 Kg/Ha.

During Rabi 1997-98 (Fig. 6.b), the H.U. of wheat remained lower than from the normal right from the initial stages and in the last stage it was lagging behind the normal by about 150 units. Due to the reduction in the H.U. in this fashion, the final yield produced lower i.e. 3800 Kg/Ha.

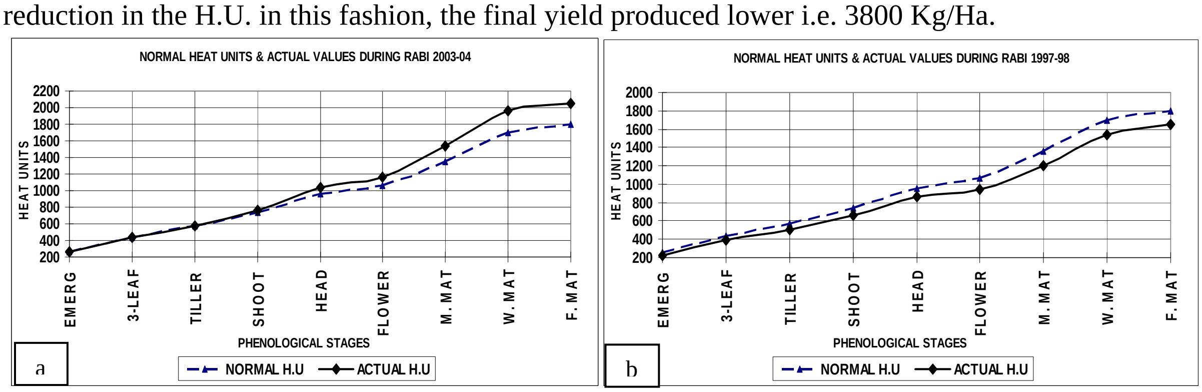


Fig 6.(a). Normal and observed heat units for wheat crop during Rabi 2003-04 and **(b)** 1997-98.

Critical Heat Units

The behavior of heat units accumulated up to or at the beginning of some important phonological stages and the final yield produced during different Rabi seasons is being discussed. We start from the stage "Tillering", which is very important as new tillers are produced during this period.

It can be seen from the Figure 7.a, that most of the time whenever heat units remained higher than the normal, a better yield produced and vice versa. Although for a few years this idea does holds good as heat unit are not the only driver of growth and development.

Shooting is very important stage in the life cycle of wheat cop. At shooting also (Fig. 7.b), the higher heat units than normal resulted a better yield in the end and vice versa, except for a few seasons. This rule holds well in the seasons with extra ordinary yield response and also for the seasons with poor yield response.

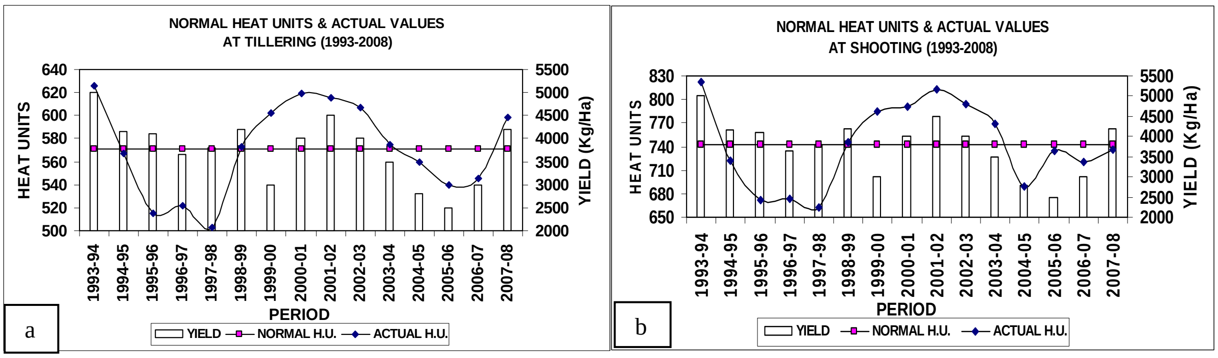


Fig 7.a & b: Normal & actual H.U accumulated for wheat crop up to Tillering and Shooting respectively and yield produced in the last 15 years.

It is well known fact that if favorable temperature conditions for wheat at heading gives rise to higher number of spikes per plant, consequently good yield may be expected in the end. In the last 15 years at heading also (Fig. 7.c), whenever the actual heat units remained higher than the normal values, the yield harvested was good in the end, except for a few seasons. It is also very important stage for wheat crop, as during this the spikes are produced. Favourable thermal regime enhances the number of grains per spike as well as better size and weight of the grains resulting into better yield.

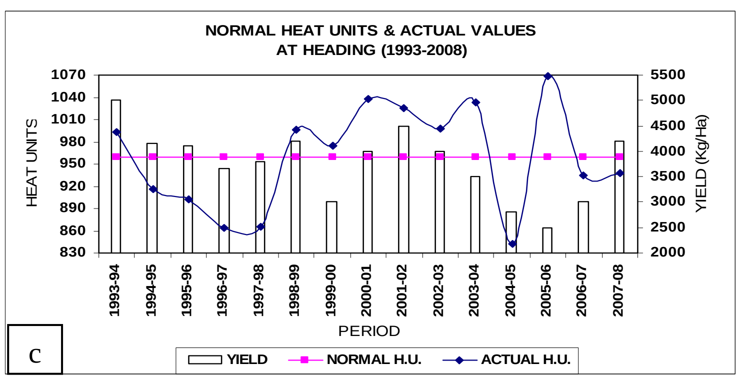


Fig 7.c: Normal & actual H.U accumulated for wheat crop when the Heading started and yield produced in the last 15 years.

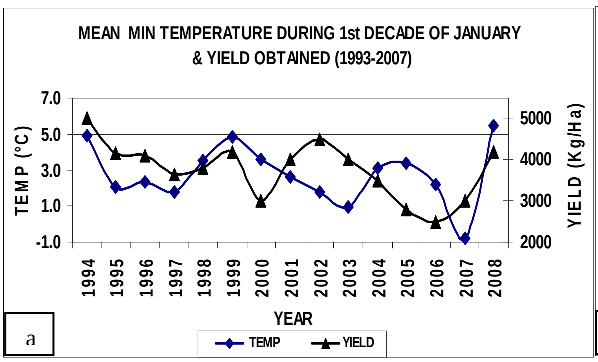
Minimum Temperature

There are many disadvantages of freezing temperatures like the decrease in photosynthesis, decrease in the export of Carbon Dioxide from the leaves, slower intake of nutrients etc. Although, mild frosts are not so dangerous for green plants but heavy frosts can cause leaf's death. Also the cold is considered more dangerous to the plants growth and in turn to the final yield at more advanced stages. Dormancy period may be produced some time in the crop's life cycle, if very low temperatures sustained for several days.

In Potohar region generally the frost phenomena is seen during the colder months. One of the best indicators for cold, frosts etc is minimum air temperature. Therefore, minimum temperature is studied on decadal basis as monthly value cannot show the whole picture of its impact on wheat growth. The approaches being used here are general comparison and regression.

Correlation based analysis of mean minimum temperature (T_N) the final yield in the1st decade of January (Fig. 8.a) was carried out. It can be seen that in the years when it remained 2°C or above in this decade, the final yield produced was good or above normal. Therefore, we may conclude, if minimum temperature stays at 2°C or higher then good yield may be expected. But this theory may be best explained by the regression method.

Regression analysis shows that with the increase in minimum temperature, the grain yield has also increased in the last 15 years period. In the figure 8.b, mean minimum temperature during the first decade of January is plotted against the respective yield obtained, the yield values are also shown at each point. This approach also confirms the idea or assumption that the final yield will be higher if minimum temperature in first decade of January remains higher.



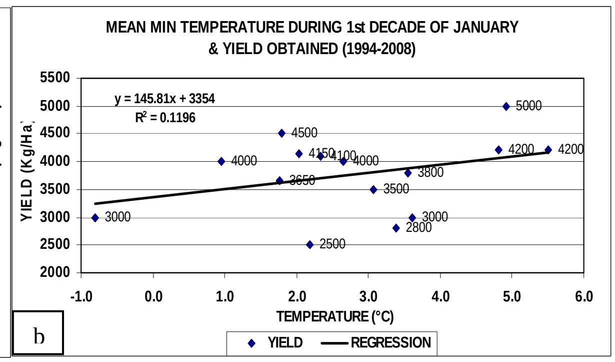
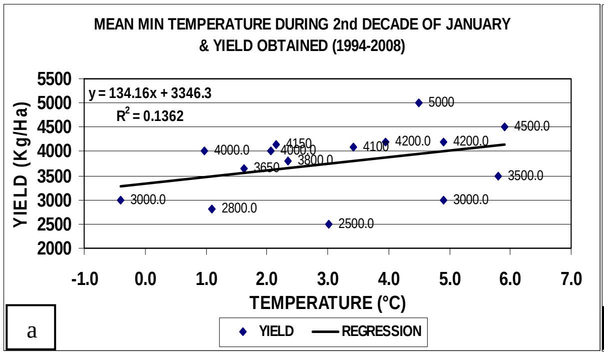


Fig.8.(a.). Mean mininimum temp in 1st decade of January verses yield during 1994-2008 (comparison) and **(b)** regression.

By using the regression approach for second decade of January it can be seen that with the increase in minimum temperature, the grain yield also increased in the last 15 years period. In the Figure 9.A, mean minimum temperature during the second decade of January is plotted against the respective yield produced, the yield values are also shown at each point also. As the value for "R^2"is "0.14" we may say that the regression result is about 37 % which indicates a considerable relationship. Thus we say that the final yield may be higher if minimum temperature in second decade of January remains higher.

By using the regression approach for first decade of February it may be seen that now with the decrease in minimum temperature, the grain yield has increased in the last 15 years period. In the Figure 9.B, mean minimum temperature during the first decade of February is plotted against the respective yield produced, the yield values are also shown at each point also. As the value for "R^2"is "0.22" we may say that the regression result is about 47 % which is sign of a good relationship. Thus we say that the final yield may be higher if minimum temperature in first decade of February remains lower.



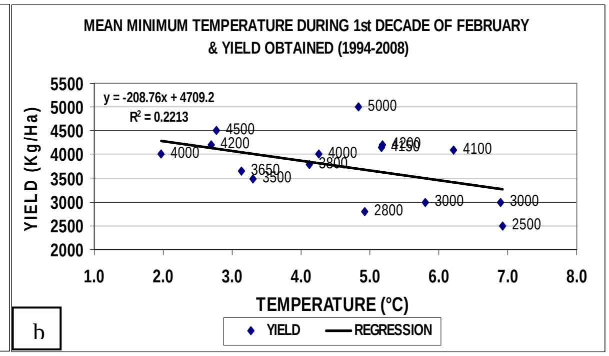


Fig.9.(a). Mean minimum temp in 2nd decade of January and **(b)** 1st decade of February verses yield during 1994-2008.

Maximum Temperarure

Maximum temperatures are some times become responsible for limiting wheat yield, by giving rise to mean daily temperatures. With the increase in mean daily temperatures, the heat units will be increased earlier. Accordingly wheat will acquire the heat units required for maturity stage well before time or much earlier than the requirement. In turn the crop will be ready to harvest earlier but grain yield will remain definitely lower. Maximum temperatures actually accelerate the plant development and affect the floral organ, processes of fruit formation & photosynthesis. Now we discuss and analyze the mean maximum temperatures (T_X) on decadal basis with respective yield produced during the last 15 years.

In Figure 10, mean maximum temperature as observed during the 2nd decade of November is plotted against the respective yield produced. It can be seen from the above Figure that maximum temperature shows good result relative to the final yield. Value for R^2 is shown as “0.15” and we may say that the regression result is about 39 %. It means that with the increase in maximum temperature during 2nd decade of December, the final yield is expected to be produced as good or above average.

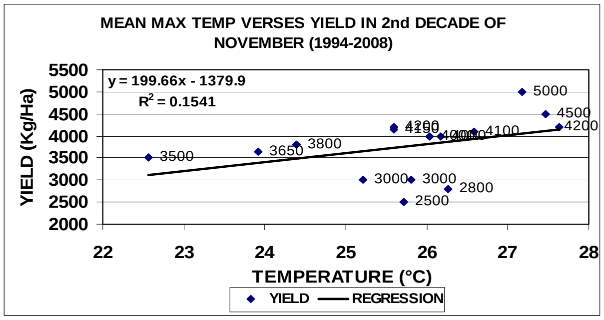


Fig.10: Mean max temp in 2nd decade of November verses yield during 1994-2008.

On Comparing mean maximum temperature (T_X) against the final yield in 2nd decade of December it can be seen that when ever it remained up to 19 °C, the final yield produced good and vice versa. Therefore, we may assume, if maximum temperature stays 19°C or lower then finally good yield may be expected. But this theory may be better explained by the regression method.

In the Figure 11.A, mean maximum temperature as observed during the 2nd decade of December is plotted against the respective yield produced. It can be seen from the above Figure that maximum temperature shows good result relative to the final yield. Value for R^2 is shown as “0.19” we may say that the regression result is about 44 %. It means that with the decrease in maximum temperature during 2nd decade of December, the final yield produced as good or above average.

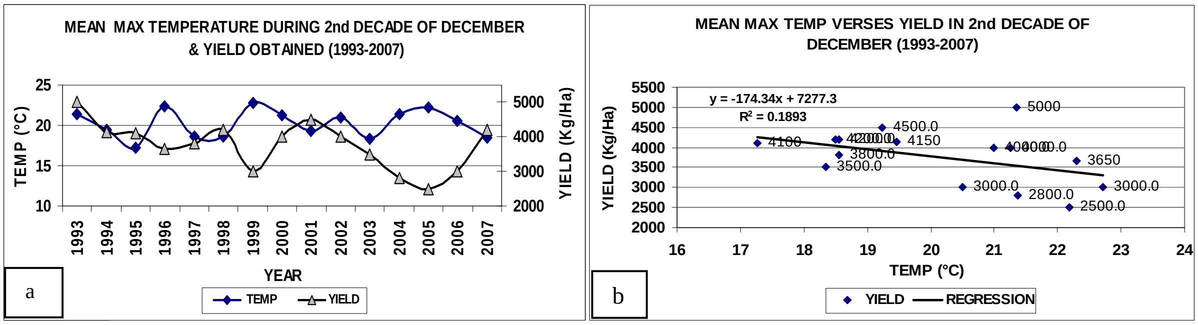


Fig. 11.(a). Mean maximum temp in 2nd decade of December verses yield during 1993-2007 (comparison) and **(b)** regression.

As it is recommended that the yield forecast for wheat crop should be made at least after six weeks of the sowing or before two month to harvest, therefore we are discussing all the parameters till the end of February, for each Rabi season. And it is seen that besides these two decades (2nd decade of November & December), maximum temperature does not show any out standing results relative to final yield. Although temperature has its by products in the form of degree days or heat units which have already been discussed.

Sunshine Hours

Duration of bright sunshine hours (or generally sunshine hours) is also very important factor relative to the final yield, as they affect greenery or water contents directly. These play a major role in driving temperature and consequently ETo in a particular area. And it is a well known fact that temperature and ETo are very important factors for the growth of any crop, especially in rainfed areas. Also photosynthesis process (a key player for healthy growth of a crop) is mainly dependant on good sunshine and less cloudiness. That is why sunshine hours are included in the discussion and being examined on decadal basis against the final yield produced during last 15 years. For better elaboration the dependency of the final crop on sunshine hours, regression method is once again being employed.

It can be seen from the Figures 12 & 13.A, that during the 3rd decade of January and 1st decade of February we got a good yield with higher sunshine hours. The value for R^2 is "0.52", for decade-III of January which is a rather out standing result.

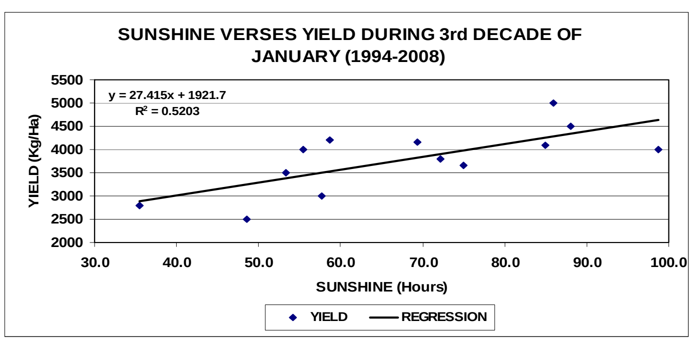


Fig.12: Total sunshine hours during 3rd decade of January verses yield during 1994-2008.

Therefore, on the 15 years data base we can say that for a better final yield of wheat crop sunshine for long durations is required during the 3rd decade of January & 1st decade of February. Therefore on the basis of the statistics of last 15 years, for a better yield of wheat crop the sunshine duration should be longer during these decades.

The correlation abruptly changed in the 3rd decade of February (Fig.13.b) in which with the lowering of sunshine the final yield obtained has increased in the last 15 years.

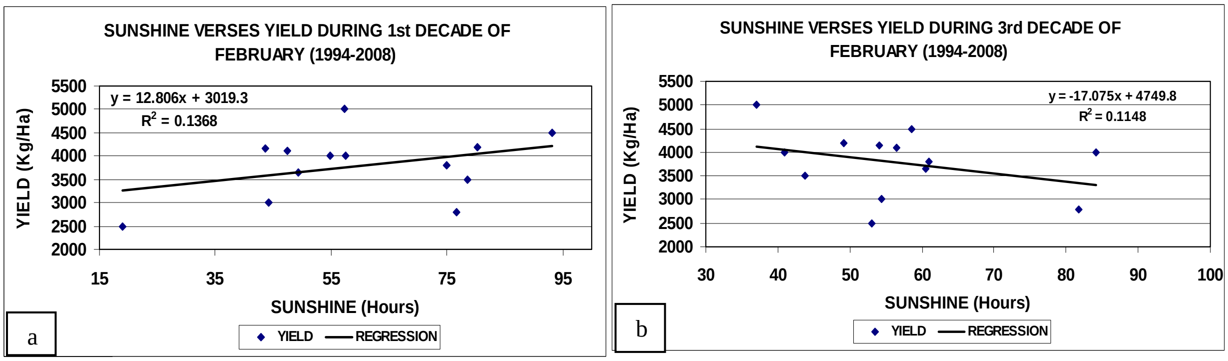


Fig.13.(a). Total sunshine hours during 1st decade and **(b)** 3rd decade of February verses yield during 1994-2008

And again in 1st decade of March, the final yield gain has been increased with the increase in sunshine hours (Fig. 14.a). The value for R^2 is above 0.31 which is indication of a good relationship.

Also it is seen that the theory of increasing yield with sunshine, has supported by the Figure for relative humidity verses yield (Fig. 14.b) for 2nd decade of March, in the last 15 years As the sunshine & relative humidity are reciprocal to each other, increase in sunshine generally cause decrease in relative humidity and vice versa.

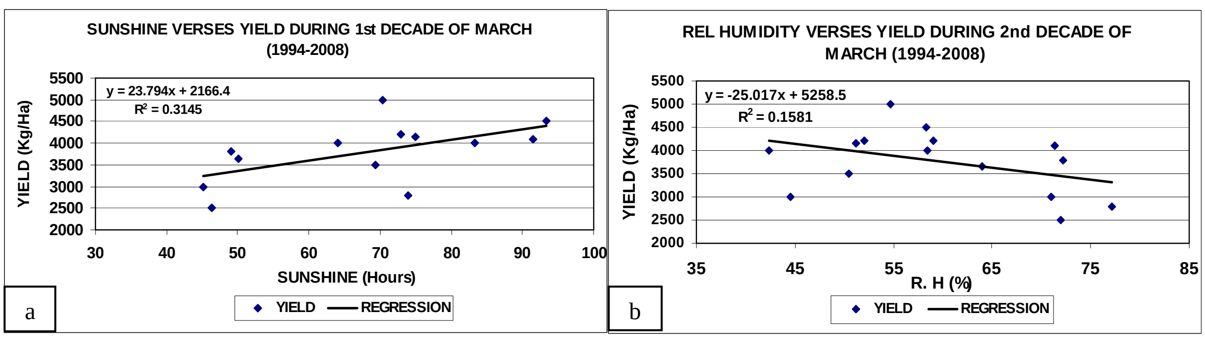


Fig.14.(a). Total sunshine hours during 1st decade and **(b)** 2nd decade of March verses yield during 1994-2008

Reference Crop Evapotranspiration

As reference crop evapotranspiration (ETo) is calculated on the basis of some basic meteorological elements like mean daily temperature, relative humidity, bright sunshine hours and wind speed (Blaney-Criddle method), therefore any of its impact on the final yield may be due to combined effect generated by all these elements or individual effects of any of the elements. The pattern of ETo in the first four months on decadal basis for some important seasons is being analyzed along with the average ETo in the last 15 years.

In the Figure 15.A, it can be seen that during the early stages and 2nd decade of December ETo was higher than the normal, but it become a bit lower in 2nd decade of January and continues till the end of February. In this season the final yield was 5000 Kg/Ha, which is the highest in the last 15 years.

In Rabi 2001-02 (Figure 15.B) also the ETo was a little higher than the normal pattern, but then decreased and marched almost along the normal during last 4 decades till the end of February. The final yield in this season was also very good i.e. 4500 Kg/Ha.

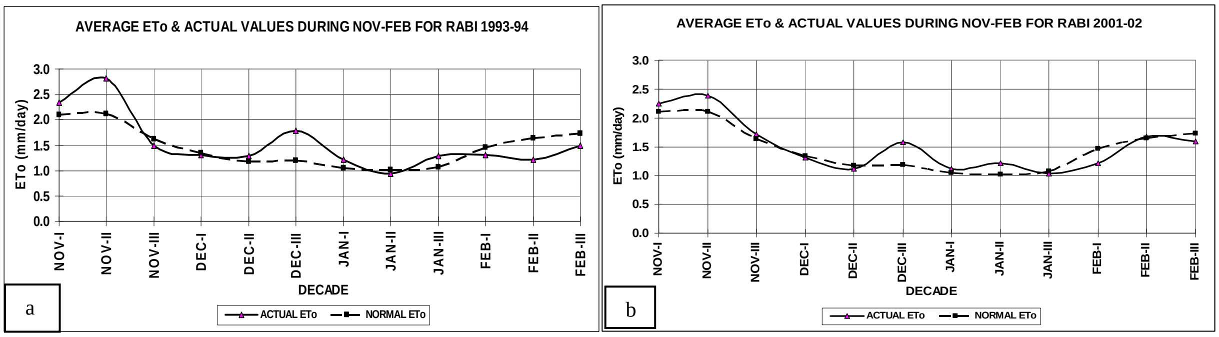


Fig.15.(a). Average & actual values of decadal ETo during Nov-Feb for Rabi 1993-94 and **(b)** for Rabi 2001-02.

The seasons which are discussed in the above paragraphs were those in which very good amount of yield was obtained, the following discussion is regarding some low or average yield seasons in the last 15 years.

In Rabi 1997-98 (Figure 16.A), during early stages ETo was very lower than the normal and continues with almost the same pattern till the end of December. From January, it became closer to the normal and ends with a little lower value. At the end of this season an average amount of yield obtained ie. 3650 Kg/Ha.

In Rabi 2005-06 (Figure 16.B), ETo started with the normal values and continues the same pattern till the 1st decade of January, then it increased ends with a littler higher to the normal. At the end of this season a very low yield produced that is 2500 Kg/Ha.

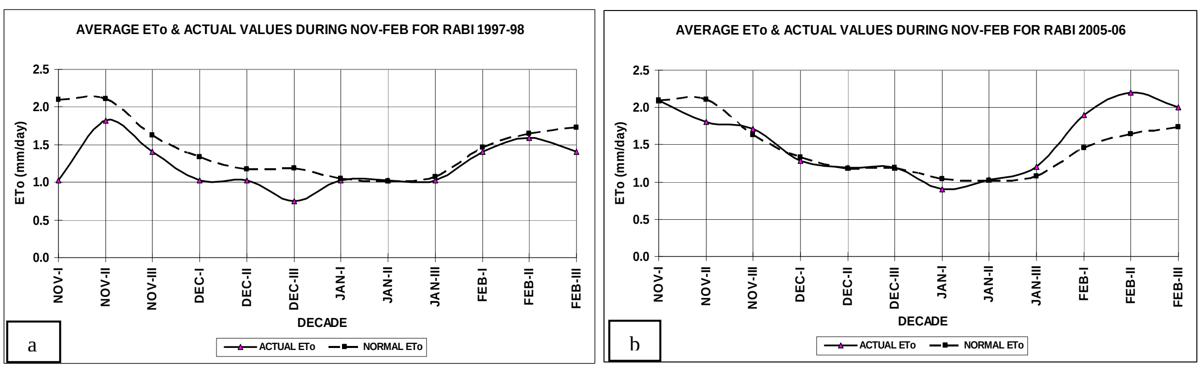


Fig.16.(a). Average & actual values of decadal ETo during Nov-Feb for Rabi 1997-98 and **(b)** for Rabi 2005-06.

From the above Figures it can be seen that when ever ETo remain closer or a bit lower than the average or normal values during February, besides remaining higher in the early stages, the final yield was good or above average. But if it became higher than the normal in some last decades of January/February then a lower amount of yield produced.

Conclusion

There are a number of meteorological parameters significant for the growth and development of wheat crop in rainfed areas of Potohar. But significance of some of these may become more pronounced at some particular stage or period in the crop's life cycle. In this study it has been observed that at a particular time some meteorological parameters act as the main actor for the physical growth of wheat crop and the final yield in the end. These parameters were studied individually against the final yield obtained and the following conclusions were made.

- During the 1st & 2nd decade of January, the moderate amount of rainfall (approximately up to 40 mm) helps to get a better yield in the end. Heavy rains in these decades may have adverse effects on the final yield.
- Throughout the wheat grown season, if rainfall exceeds 120 mm then the final yield obtained may be good or above average.
- Reproductive stage (heading to grain formation) is the most critical period in the life cycle of wheat crop. A slight shortfall or excess of water produces drastic changes in the economic yield of the crop. Therefore, for optimum yield good rainfalls with higher and scattered rainy days at this stage are favourable.
- Heat units during initial stages and particularly at the beginning of reproductive stages should be equal to or a little bit higher than the normal values i.e. 960 & 1067 for Heading & Flowering respectively. Also at the final stage the heat units should be within the range 1650 to 1950. If these requirements are fulfilled simultaneously then a better yield may be expected.
- Mean minimum temperature should be higher during first two decades of January and lower in the 2nd decade of February, for a better yield in the end. Higher than normal temperatures in February cause significant reductions in wheat yield.
- During the 3rd decade of January & 1st decade of March higher duration of bright sunshine is favourable for a better yield.
- When the value of ETo remain a little higher than the normal during some initial decades and in the last decades of February equal or slightly lower than the normal, then a better yield may be expected in the end.

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