Agric Res J **59** (6) : 1070-1077, *December* 2022
DOI No. 10.5958/2395-146X.2022.00149.1

EFFECT OF WESTERN DISTURBANCES, TEMPERATURE AND RAINFALL ON WHEAT YIELD IN PUNJAB

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ABSTRACT

The maximum and minimum temperature and rainfall analyses during reproductive period (February and March) of wheat crop for Ludhiana, Ballowal Saunkhri and Bathinda were conducted from 2011-12 to 2016-17. Wheat yield of Ludhiana (1990-91 to 2016-17), Bathinda (2001-02 to 2016-17) and Ballowal Saunkhri (1990-91 to 2016-17) were collected from the Statistical Abstracts, and corresponding meteorological and western disturbances (WDs) data were collected from Punjab Agricultural University, Ludhiana/ Research stations and India Meteorological Department, Chandigarh. The relationships between number of western disturbances and wheat yield for each location were conducted. It has been observed that the western disturbances' frequency increased from 2012-13 to 2015-16 and again decreased in 2016-17 in Punjab. Correlation analysis between wheat yield and WD indicates significant and negative values at Ludhiana. The highest R^2 value of 0.88 was observed at Ludhiana. The increased frequency of western disturbance during February and March had a significant negative effect on wheat yield. The years having a smaller number of WDs recorded the highest yield and vice-versa at all the locations. Low minimum and maximum temperatures during February and March favoured the higher yield at all the three locations. The results also indicate that during the highest yield years, the rainfall at reproductive phase was very low at all the locations.

Keywords: Rainfall, Temperature, Western disturbance, Wheat yield

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On an average 3-6 western disturbances move across India in each month of the season. Out of these about 50 percent do not affect the area south of 30^0 N. The WDs are the major cause of rain and snow in north India during winters. They usually begin as low-pressure systems near the Atlantic Ocean and Europe. They gradually travel across the middle-east from Iran, Afghanistan and Pakistan to enter the Indian subcontinent.

It has been observed that the maximum frequency of western disturbances is during the period from December to April. The crop growth and yield are affected mainly by air temperature, soil temperature, relative humidity, solar radiation, wind, cloudiness and precipitation. All these parameters are modified with the arrival of western disturbance. In north India, the production of *rabi* crops is adversely affected in the absence of western disturbance, even under irrigated conditions. It causes cloudy weather, snowfall and rainfall in many parts of north India during *rabi* season. Wheat crop sown under rainfed conditions is greatly benefited by the arrival of WD in our country. The rainfall caused by WD during October-November is beneficial for sowing of wheat crop in those areas where the irrigation facilities are not available. WD contributes up to 15 per cent precipitation over the north-western region. This precipitation reduces in frequency and intensity southwards and eastwards (Yadav *et al.,* 2012).

Fluctuations in temperature and precipitation influence crop productivity across the planet. With episodes of extreme climate becoming increasingly frequent, buffering crop production against these stresses is a critical aspect of climate adaptation (Davis *et al.,* 2019). A change in optimal temperature during its vegetative or reproductive phase adversely affects the onset and duration of phenophases and yield of crop (Narayanan 2018). Wheat yield appears to be becoming more sensitive to minimum temperature, especially during the post anthesis period. Mean wheat yields for the period 1980-2011 declined by 7 per cent (204 kg/ha) for 1°C rise in minimum temperature (Rao *et al.,* 2015). Gupta *et al.* (2010) concluded that abrupt rise in temperature during March 2010 caused significant reduction in wheat yield over the Indo-Gangetic Plains of India. Similarly Mukherjee *et al.* (2019) also concluded that the wheat yield loss corresponds to the increase in the number of days with a temperature above 35°C during the maturity stage (March). In India, particularly Punjab, farmers by and large delay wheat sowing due to intensive cropping system, which pushes the grain

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Date of receipt: 28.07.2021, Date of acceptance: 31.12.2022

filling stage to high temperature stress. This increased temperature not only hastens the phenological stages of crop development but also reduces duration of grain filling stages thereby lowering the grain yield and its quality (Farooq *et al.,* 2011 and Lobell *et al.,* 2012). Hailstorm and heavy rainfall at late reproductive stage cause heavy damage to the crop. The low crop yield was recorded in the years having higher rainfall and high yield was recorded when the rainfall was low during crop season as reported by Dhaliwal *et al.* (2006) and Kaur and Dhaliwal (2018).-Keeping all this in view, the analysis of historical WDs, temperature and rainfall during the reproductive phase of wheat and wheat yield variability at different locations viz. Ludhiana, Bathinda and Ballowal Saunkhri were conducted.

MATERIALS AND METHODS

The historical data on wheat yield of Ludhiana (1990-91 to 2016-17), Bathinda (2001-02 to 2016-17) and Ballowal Saunkhri (1990-91 to 2016-17) were collected from the Statistical Abstract. The corresponding meteorological data viz. maximum temperature, minimum temperature and rainfall of these locations were collected from Regional Research Station, Bathinda, Regional Research Station, Ballowal Saunkhri and PAU, Ludhiana. Data on western disturbance in Punjab (1990-2017) during wheat growing season were collected from the Regional Meteorological Centre, India Meteorological Department, Chandigarh. The maximum and minimum temperatures and rainfall analysis during reproductive period (February and March) for Ludhiana (30.9010° N, 75.8573° E), Ballowal Saunkhri (31.0993° N, 76.3870° E) and Bathinda (30.2110° N, 74.9455° E) were conducted for the period from 2011-12 to 2016-17. Three ranges of maximum temperature viz. < 20°C, 20-25°C and > 25°Cin February month, and three ranges in March month <25°C, 25-30°C and > 30°C and minimum temperature *viz.*<8°C, 8-13°C and >13°C in February month and <10°C, 10-15°C and >15°C in March month were selected for analysis. The number of days in different ranges of maximum and minimum temperatures during February and March months were compiled for these locations.

Similarly weekly rainfall during the same period for these locations was also analyzed. The correlation and regression analysis between wheat grain yield and number of WDs was conducted using EXCEL.

RESULTS AND DISCUSSION

Maximum and minimum temperatures

The comparison of different meteorological parameters *viz.* maximum temperature, minimum temperature and rainfall during the reproductive period of wheat crop (February and March) from 2011-12 to 2016-17 for Ludhiana, Ballowal Saunkhri and Bathinda was conducted.

Three ranges of maximum temperature viz. < 20°C, 20-25°C and > 25°C in February month, and three ranges in March month <25°C, 25-30°C and > 30°C were selected for analysis. Total number of days in particular during February and March were counted separately.

Maximum temperature during reproductive phase of wheat (February and March)

Ludhiana

The comparison between the highest (2011-12) and the lowest (2014-15) wheat yield years of Ludhiana indicates that during the highest yield year, the temperature during the month of February remained less than 20°C for 18 days as compared to 3 days during the lowest yield year. The temperature ranged between 20-25°C for 11 days during the highest yield year compared to 21 days during the lowest yield year (Table 1). During the highest yield year the maximum temperature remained less than 25°C for 9 days in

Table 1. Range of maximum temperature during reproductive period (February and March) of wheat at Ludhiana

Range	Maximum temperature range (No. of days)					
	February					
T_{max}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 20	18	9	18	3	1	1
20-25	11	19	10	21	21	17
> 25	0	0	0	4	7	10
	March					
< 25	9	3	16	15	3	12
25-30	13	24	13	10	18	8
> 30	9	4	2	6	10	11
Yield(kg/ha)	5375	4853	4462	4209	4583	5093

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Table 2. Range of maximum temperature during reproductive period (February and March) of wheat at Ballowal Saunkhri

Range	Maximum temperature range (No. of days)					
	February					
T_{max}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 20	8	4	10	0	0	1
20-25	18	14	18	12	18	18
> 25	3	10	0	16	11	9
	March					
T_{max}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 25	5	4	6	6	2	8
25-30	15	19	21	15	17	12
> 30	11	8	4	10	12	11
Yield(kg/ha)	4507	4220	4335	3623	4078	4142

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March as compared to the lowest yield year where it remained for 15 days. The temperature ranged between 25-30°C for 13 days during the highest yield year compared to 10 days during the lowest yield year.

Ballowal Saunkhri

During the month of February, the maximum temperature during the highest yield year (2011-12) remained below 20°C for 8 days. It has been observed that no day has a temperature less than 20°C during the lowest yield year (2014-15) (Table 2). The temperature remained mostly the same during the highest and lowest yield years during March month.

Bathinda

During February, the maximum temperature remained in between 20-25°C for 12 days during the highest yield year (2016-17) compared to the temperature range in which it remained for 19 days during the lowest yield year (2015-16) (Table 3). During the lowest yield year, maximum temperature remained in the range of 25-30°C for 20 days compared to 12 days during the highest yield year in the month of March.

The above results indicate that during the reproductive phase, maximum temperature was higher during the lowest yield years as compared to the highest yield years. This higher temperature contributed to lower yield at all the locations. Similarly Mukherjee *et al.* (2019) also reported that high temperature conditions also contribute to an overall negative effect on grain filling and physiological maturity .The crop exposed to temperatures above 34°C after the anthesis stage has a significantly low yield due to accelerated senescence, decreased rate and duration of grain filling (Aseng *et al.,* 2011 and Lobell *et al.,* 2012). The response of wheat to very high temperatures (>32°C) around anthesis can induce a non-recoverable reduction in yield by adversely affecting ovary development as well as pollen and floret viability (Pradhan *et al.,* 2012). Increase in temperature from January to March i.e. from anthesis to grain filling period causes significant yield reduction in

Table 3. Range of maximum temperature during reproductive period (February and March) of wheat at Bathinda

Range	Maximum temperature range (No. of days)					
	February					
T_{max}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 20	16	9	12	2	1	2
20-25	12	18	16	19	19	12
> 25	1	1	0	7	9	14
	March					
T_{max}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 25	7	3	11	13	2	7
25-30	14	19	18	11	20	12
> 30	10	9	2	7	9	12
Yield(kg/ha)	5000	4787	4958	4797	4679	5300

Table 4. Range of minimum temperature during reproductive period (February and March) of wheat at Ludhiana data

Range	Minimum temperature range (No. of days)					
	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
T_{min}(˚C)			February			
< 8	15	9	9	9	13	10
8-13	14	15	19	11	14	14
> 13	0	4	0	8	2	4
			March			
< 10	13	3	6	5	0	10
10-15	12	19	20	14	17	12
> 15	6	9	5	12	14	9
Yield(kg/ha)	5375	4853	4462	4209	4583	5093

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wheat as reported by Prabhjyot-Kaur *et al.* (2015) and Kaur and Dhaliwal (2018) .

Minimum temperature during reproductive phase of wheat (February and March)

Three ranges of minimum temperature *viz.*<8°C, 8-13°C and >13°C in February month and <10°C, 10-15°C and >15°C in March month were selected for analysis. Total number of days in particular range during February and March were counted separately.

Ludhiana

The minimum temperature in the month of February at Ludhiana was >13°C for 8 days during the lowest yield year (2014-15) compared to the highest yield year where no day was observed with >13°C temperature (Table 4) . In March, during the lowest yield year, the minimum temperature remained >15°C for 12 days compared to the highest yield year where it was 6 days for the same temperature.

Ballowal Saunkhri

The minimum temperature during February in the highest yield year (2011-12) remained <8°C for 21 days and it was 11 days during the lowest yield year (2014-15) (Table 5). Minimum temperature remained >15°C for 2 days during the highest yield year but in the lowest yield year it remained >15°C for 9 days in March.

Bathinda

At Bathinda, the minimum temperature remained in the range of <8-13°C for most of the period during the highest (2016-17) and the lowest yield years (2015-16) during February (Table 6).

During the highest yield year, it remained <10°C for 11 days compared to the lowest yield year where no day had temperature <10°C during the month of March. Similarly Singh *et al.* (2008) reported technology trends at Bathinda in the past 25 years and observed that wheat yield has increased at the rate of 82.1 kg ha^{-1} $year^{-1}$ when minimum temperature of 10.8°C during

Table 5. Range of minimum temperature during reproductive period (February and March) of wheat at Ballowal Saunkhri

Range	Minimum temperature range (No. of days)					
			February			
T_{min}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 8	21	12	12	11	11	10
8-13	8	14	16	12	15	12
> 13	0	2	0	5	3	6
			March			
T_{min}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 10	11	6	7	9	2	8
10-15	18	21	19	13	17	12
> 15	2	4	5	9	12	11
Yield(kg/ha)	4507	4220	4335	3623	4078	4142

Table 6. Range of minimum temperature during reproductive period (February and March) of wheat at Bathinda

Range	Minimum temperature range (No. of days)					
	February					
T_{min}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 8	19	11	13	10	17	18
8-13	10	13	15	11	9	10
> 13	0	4	0	7	3	0
	March					
T_{min}(˚C)	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
< 10	11	3	7	8	0	11
10-15	12	21	14	13	18	11
> 15	8	7	10	10	13	9
Yield(kg/ha)	5000	4787	4958	4797	4679	5300

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grain filling period resulted in the highest yield of wheat. Samra *et al.* (2012) analyzed the 12-year meteorological data at Ludhiana and reported that heatwave years which have above normal temperature had decreased the wheat yield by 4.5 per cent and wheat yield was 7.4 per cent more during cold wave year which had below normal temperature. Prasad *et al.* (2008) also reported that grain filling duration in wheat decreased by 3 and 7 days at night temperatures of 20 and 23°C, respectively, compared to a night temperature of 14°C. Prabhjyot-Kaur *et al.* (2015) revealed an increase in temperature during 4th week of January, February and 1st fortnight of March severely affected the yield of early, normal and late sown wheat crop in Punjab.

Total weekly rainfall during reproductive phase of wheat (February and March)

Total weekly rainfall during the reproductive period (February and March) for all the three locations was also analyzed.

Ludhiana

Total weekly rainfall data during February and March at Ludhiana indicates that during the highest yield year (2011-12), the total rainfall was 4.6 mm which was very low whereas in the lowest yield year (2014-15) it was 124 mm (Table 7). This high rainfall may be responsible for low yield in 2014-15.

Ballowal Saunkhri

At Ballowal Saunkhri during the lowest yield year (2014-15), the weekly rainfall in February and March was 204.4 mm compared to the highest yield year (2011-12) where it was 17.0 mm (Table 8). It indicates that rainfall during the reproductive stage of wheat is very harmful.

Bathinda

The highest yield year (2016-17) received no rainfall during February and March months compared to the lowest yield year (2015-16) where 53.4 mm rainfall was

Table 7. Total weekly rainfall (mm) during February and March at Ludhiana

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
5 (29 Jan-4 Feb)	3.4	22.6	1.0	11.6	3	5.2
6	0	1.0	2.8	0	0.8	0
7	1.2	33.4	6.1	8.4	0.6	0
8	0	33.4	16	19	7.4	0
9	0	4.0	13.6	24.8	0	0
10	0	0	4.0	8.2	23	40.8
11	0	5.4	16	36.2	14.9	0
12	0	29	9.9	0	3.2	0
13 (26 Mar-1 Apr)	0	1.2	3.3	15.8	0	0
Total Rainfall	4.6	130.0	72,7	124.0	52.9	46.0
Yield(kg/ha)	5375	4853	4462	4209	4583	5093

Table 8. Total weekly rainfall (mm) during February and March at Ballowal Saunkhri

SMW	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
5	11.2	10.8	0	11.8	2.2	3.0
6	0.0	4.0	11.6	0.0	8.4	0.6
7	0.6	12.6	15.2	4.2	1.0	0.0
8	0.0	35	2.8	43.5	3.4	0.0
9	2.3	10.8	40.2	80.2	0.0	0.0
10	2.3	0.0	9.6	4.6	18.5	33.8
11	0.7	7.2	9.0	52.1	23.3	0.7
12	0.0	32.3	10.0	0.0	1.8	0.0
13	0.0	1.0	4.0	8.0	0.0	0.0
Total rainfall	17.1	113.7	72.4	204.4	58.6	38.1
Yield(kg/ha)	4507	4220	4335	3623	4078	4142

Table 9. Total weekly rainfall (mm) during February and March at Bathinda

SMW	Weekly Rainfall (mm)					
	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17
5	0	13.4	0	9.5	0	0
6	0	1.4	4.5	0	0	0
7	0	2.4	3	0	0	0
8	0	20.2	4	2	14	0
9	0	0.5	16.6	38	0	0
10	0	0	0	2.6	8.2	0
11	0	15	1.5	39.3	31.2	0
12	0	3.8	19.4	0	0	0
13	0	3	5.4	25	0	0
Total rainfall	0	59.7	54.4	116.4	53.4	0
Yield(kg/ha)	5000	4787	4958	4797	4679	5300

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received for the same period (Table 9). So the data of all the three locations indicate that during the reproductive phase, high rainfall played a negative role for grain yield and vice-versa. Similarly Dhaliwal *et al.* (2006) reported that the rainfall received during December to March had a major effect on grain yield. They observed that low yield was recorded in the years having higher rainfall and high yield was recorded when the rainfall was low during crop season. Kingra (2016) also reported that rainfall (mm) during 6th to 12th standard meteorological week was found to be negatively correlated with wheat productivity.

Trend of western disturbances in Punjab (1990-91 to 2016-17)

It has been observed that the frequency of western disturbances increased from 2012-13 to 2015-16 and again decreased in 2016-17 in Punjab as presented in Fig.1. Maximum number of western disturbances (43) were observed during 2014-15 and minimum (16) during 2011-12 from November to March. The increased frequency of western disturbance during February and March has a significant effect on wheat yield. This is likely to cause more rainfall in these months. The frequency of western disturbances and its duration are both favourable and unfavourable depending upon its intensity and crop growth stages for overall yield as reported by Chaurasia *et al.* (1997).

Western disturbances and wheat yield

The relationship between total number of western disturbances (February and March) from 2011 to 2017 and wheat yield was worked out for Ludhiana, Bathinda and Ballowal Saunkhri. At Ludhiana, the highest yield of wheat (53.75 q ha^{-1}) was recorded during 2012 when only one WD was observed. The lowest yield (42.09 q ha^{-1}) of wheat was recorded in 2015 which may be due to the maximum number (24) of western disturbances (Fig. 2). The lowest yield (37.12q ha^{-1}) and highest yield (51.62 q ha^{-1}) at Ballowal Saunkhri were attained

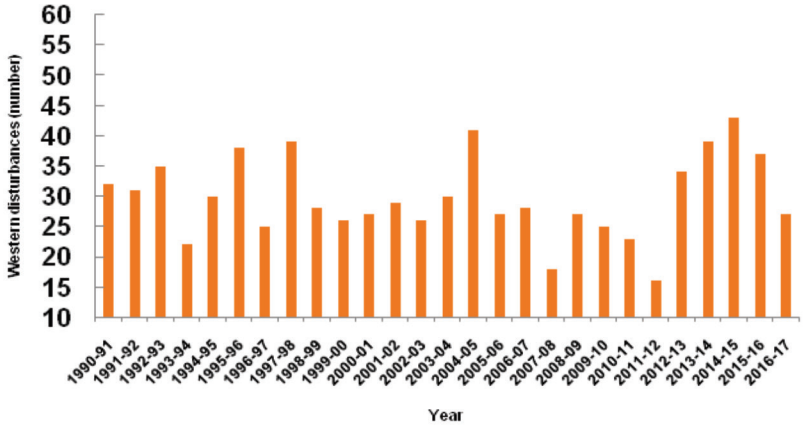

Fig. 1. Trend of western disturbances (from November to March) in Punjab (1990-91 to 2016-17)

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during 2015 and 2012 respectively. The maximum number of western disturbance (24) was recorded during 2015 whereas the minimum (1) during 2012 (Fig. 2). At Bathinda maximum yield was recorded during 2017 and the total number of western disturbances was eight. The lowest yield during 2011 at Bathinda was (46.09 q ha^{-1}) and total number of western disturbance was eleven (Fig. 2). It indicates that during higher yield years, the WDs were low in number and vice-versa for all the locations.

Correlation analysis

The correlation coefficients of total western disturbances (February and March) with wheat yield are presented in Table 10. At Ludhiana and Ballowal Saunkhri, total western disturbances showed a significant negative correlation with wheat yield. It indicates that more rainfall/cloudy weather due to WD during March are unfavouable for wheat yield. The significant negative correlation was found during March at Ludhiana from 1990-91 to 2000-01 and 2000-01 to 2016-17.

Regression analysis between western disturbances and wheat yield

The regression analysis was done between number of western disturbances and wheat yield during 2011 to 2017 for different locations of Punjab. and presented below. The highest R^2 value (0.88) was observed at Ludhiana followed by Bathinda (R^2=0.40) and Ballowal

Fig. 2. Number of western disturbances during February and March and wheat yield at Ludhiana (top), Ballowal Saunkhri (middle) and Bathinda (bottom)

Table 10. Correlation coefficients of total western disturbances during February and March with wheat yield

Month	1990-91 to 2000-01		2000-01 to 2016-17			1990-91 to 2016-17	
	Ludhiana	Ballowal Saunkhri	Ludhiana	Bathinda	Ballowal Saunkhri	Ludhiana	Ballowal Saunkhri
February	-0.08	-0.02	-0.41	0.09	-0.09	-0.28	-0.03
March	-0.61*	-0.39	-0.55*	0.09	-0.41	-0.50**	-0.27

* - at 0.05 level of significance
** - at 0.01 level of significance

Saunkhri (R^2 = 0.25).

For Ludhiana Y= 54.59-0.47WD (R2=0.88)
For Bathinda Y= 51.62-0.16WD (R2=0.40)
For Ballowal Saunkhri Y= 49.65-0.33WD (R2=0.25)
Y- Grain yield (q/ha)
WD- Total number of Western disturbances during February and March

In conclusion, the results indicate that during the highest yield years the rainfall at reproductive phase was very low at all the locations. Low minimum and maximum temperatures during February and March favoured the higher yield at all the three locations. The increased frequency of western disturbance during February and March has a significant negative effect on wheat yield. The wheat yield was highest during the years having a smaller number of WDs and vice-versa at all the locations.

Authors' contribution

Conceptualization of research work and designing of experiments (LKD, SK); Execution of field/lab experiments and data collection (JK, SP); Analysis of data and interpretation (JK, LK, SK, SP); Preparation of manuscript (JK, LK)

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