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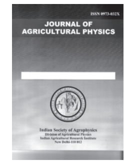

Research Article

Weather Parameters for Higher Rice Productivity in Central Punjab

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ABSTRACT

Rice is an important crop of Punjab and is important for food security of India. Productivity of rice is influenced by many factors and among them weather is the most important. In order to determine optimum ranges for weather parameters leading to higher rice productivity a study was conducted at Punjab Agricultural University, Ludhiana, Punjab. The historical (1971-2018) average rice productivity of Ludhiana district and weather data recorded at PAU, Ludhiana was used for the study. The historical rice productivity data was detrended to remove the increasing trend in productivity due to advancement in production technologies. Out of the detrended productivity data, 15 years of highest detrended productivity was selected and corresponding weekly averages of weather parameters were used to calculate mean and standard deviation. The weekly optimum ranges of weather parameters were calculated by mean ± standard deviation of the selected 15 years. The ranges were calculated from 20th to 40th standard meteorological week (SMW) corresponding to a period ranging from nursery sowing to harvesting of rice crop. The results showed that at Ludhiana for high rice productivity during nursery stage extending from 20-24 SMW, the optimum average range for maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and bright sunshine hours are 36.6-42.2 °C, 21.4-25.8 °C, 45.1-71.2%, 17.9-35.4% and 9.3-12.1 hours, respectively. The optimum average range of these parameters during vegetative stage are 32.6-36.5 °C, 24.7-27.1 °C, 75.6-89.2%, 50.0-72.4% and 5.1-9.9 hours, respectively. The optimum average range of these parameters during reproductive stage are 31.9-35.0 °C, 30.5-23.7 °C, 81.9-93.6%, 43.4-65.8% and 7.4-11.1 hours, respectively

Key words: Rice, Temperature, Relative humidity, Sunshine hours, Range, Crop-weather insurance, Punjab

Rice (*Oryza sativa* L.) is one of the most important cereals. It is considered as the second-largest crop of the world and is the staple food for more than half of the global population. (Mondal *et al.,* 2019). Rice is second to wheat among the major grain crops grown in India. In India rice was sown on an area of 43.8 million hectares with a production of 176.8 million tonnes in the year 2019-20 (Anonymous, 2022). Global food security now a day's faces a major threat due to the increasing population and climate change. Wide array of abiotic stresses affect the different biochemical and physiological mechanisms of the plants and thereby reducing crop productivity (Petrov *et al.*, 2015). Among abiotic factors weather is one of the most fluctuating parameters responsible for yearly variation in productivity of crops. Significant change in temperature, humidity, solar radiation has been noticed in many parts of the world. Crop growing under optimum weather conditions is expected to give high yield.

The optimum temperature for the normal development of rice plant ranges from 27-32 °C (Yin

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et al., 1996). Spikelet sterility is greatly increased at temperatures higher than 35 °C (Satake and Yoshida, 1978; Matsui *et al*., 1997) which is the critical maximum temperature in rice. Night temperature of less than 19 °C is the critical low temperature for inducing grain sterility in rice (Abeysiriwardena *et al*., 2002). A relative humidity of 85-90% at the heading stage induces almost complete grain sterility in rice at a day/night temperature of 35/30 °C (Abeysiriwardena *et al*., 2002). Similarly, optimum limits of other weather parameters are available in literature. But the values may vary with location and cultivars being used. Moreover, for policy planners these values may be of little use as they are interested in yield at district, region or state level. In actual field conditions at farmers' level there is a lot of variation in sowing date, varieties being sown, management practices, etc.

Rice is an important summer season cereal crop in Punjab state and weather plays a vital role in influencing its growth and yield. So the aim of the present study was to determine optimum ranges of different weather parameters at weekly intervals for higher rice productivity in Ludhiana district (in central Punjab of India). Moreover these ranges are helpful while issuing the yield forecasts for the policy planners as well as in crop insurance schemes.

Materials and Methods

Data used

The historical (1971-2018) rice productivity data of Ludhiana district was collected from Statistical Abstracts of Punjab. The daily weather data recorded at Agrometeorological Observatory of Punjab Agricultural University, Ludhiana was used for the study.

Detrending of rice productivity

The rice yield during 1971 was 1800 kg ha^{-1} which has increased to 4815 kg ha^{-1} during 2017 due to improved crop production and protection practices. Assuming that the crop management practices does not change on yearly basis, the year to year variability in yield of rice is the result of the favourable and unfavourable weather experienced by the crop during various phases of the growth. Hence, to evaluate the only effect of weather on rice productivity after separating the positive effect of technological advancement (improved production and protection practices) the detrending of the rice productivity data needs to be done. Otherwise, if the actual productivity data were used it would exclude all the early years of the data series and will lead to selection of recent years (having higher temperatures and relative humidity and on the other hand reduced bright sunshine hours as compared to earlier years). The results will be biased due to the impact of technological advancement and will not represent actual weather limits. The detrending of rice yield was done by using the methodology explained by Gommes and Hoefsloot (2017). The detrending of yield involved two steps. The first step is the fitting of a smooth curve through the actual yield data. In the second step the detrended yield (Fig. 1) was calculated.

Selection of detrended high productivity years

Over the past 48 years (1971 to 2018) the perusal of the detrended productivity data (Fig. 1) showed that there are yearly increases and decreases in productivity. These ups and downs were due to favourable / unfavorable weather that prevailed during that particular year and has no linkage with advancement of technology, as the technology does not changes in a single year. So out of the detrended productivity data of 48 years, the 15 years (1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1986, 1987, 1988, 1990, 2005 and 2010) of highest detrended productivity were selected for further analysis. All these years had rice productivity more than 5021 kg ha^{-1}.

Weekly ranges of weather parameters

The weekly averages of weather parameters corresponding to the 15 years of highest detrended productivity (≥5021 kg ha^{-1}) were used to calculate weekly means and standard deviations. The weekly optimum ranges of weather parameters were calculated by mean ± standard deviation as this range would include approximately 68 per cent of the high yielding years after excluding the extreme high and low values of weather parameters. The ranges were calculated starting from 20th standard meteorological week (SMW) upto 40th SMW as these weeks cover the period of normal sowing upto harvest of rice crop

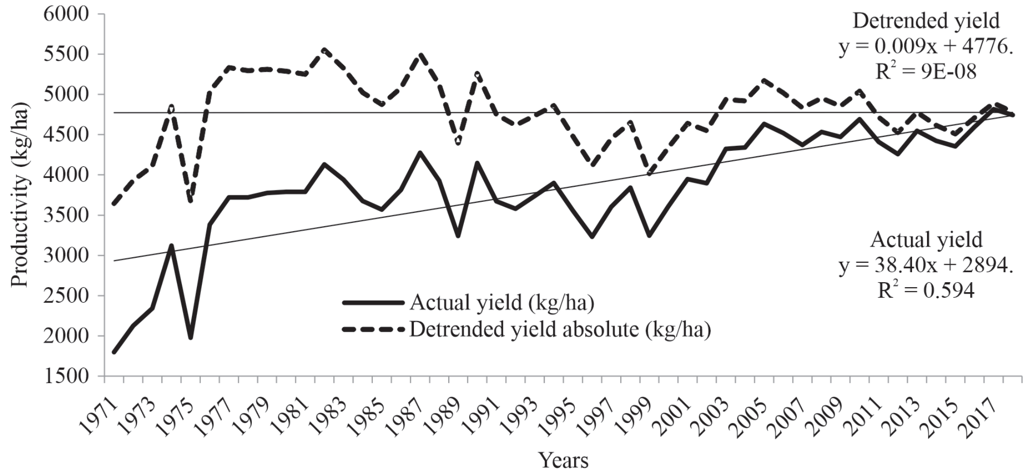

Fig. 1. Comparison of actual and detrended rice productivity of Ludhiana district

and the weather outside these weeks had little effect on rice productivity.

The methodology followed in the present study was similar as followed by in our previous study (Sandhu *et al*., 2018) in wheat crops. In previous study (Sandhu *et al*., 2018) optimum temperature ranges for wheat were worked out but in the present study optimum ranges for all the weather parameters were determined.

Validation of optimum range of weather parameters for higher productivity

The optimum ranges of weather parameters for higher rice productivity were validated using the weather and rice productivity data of Ludhiana district corresponding to two low (2014 and 2015) and two high (2017 and 2018) yield year. These low and high yields were selected with the assumption that during the five years starting from 2014 to 2018, agronomic crop management practices would have remained same in the district and only prevailing the favourable / unfavourable weather conditions would be reason for high and low yield of rice crop.

Results and Discussion

Optimum range of temperature for high productivity of rice

Nursery stage (20-24 SMW): The average optimum range for maximum and minimum temperatures varied between 36.6-42.2 and 21.4-25.8 °C, respectively (Table 1). The lower and upper limit of optimum maximum /minimum temperature varied between 35.3-38.1 and 41.1-42.8 °C / 19.7-22.9 and 24.4-26.8 °C, respectively.

Vegetative stage (25-34 SMW): The average optimum range for maximum and minimum temperatures varied between 32.6-36.5 and 24.7-27.1 °C, respectively (Table 1). The lower and upper limit of optimum maximum /minimum temperature varied between 31.4-36.0 and 34.2-41.5 °C / 23.9-25.3 and 26.3-29.1 °C, respectively.

Reproductive stage (35-40 SMW): The average optimum range for maximum and minimum temperatures varied between 31.9-35.0 and 20.5-23.7 °C, respectively (Table 1). The lower and upper limit of optimum maximum /minimum temperature varied between 31.0-32.3 and 34.4-35.5 °C / 17.2-23.1 and 20.6-25.7 °C, respectively.

Previous studies (Jagadish *et al*., 2007; Morita *et al*., 2004) reported that in rice threshold temperatures of 33.7 °C and 34.0 °C cause poor anther dehiscence, sterility and yield reduction respectively. Quite similar to our results Abeysiriwardena *et al*. (2002) proposed that minimum temperature less than 19.0 °C is the critical low temperature for inducing grain sterility in rice.

Optimum range of humidity for high productivity of rice

Nursery stage (20-24 SMW): The average optimum range for morning and evening relative humidity varied between 45.1-71.2% and 17.9-35.4%,

Table 1. Weekly range of weather parameters for high productivity of rice in central Punjab (Ludhiana)

Stages	SMW	Maximum temperature (°C)			Minimum temperature (°C)			Morning relative humidity (%)			Evening relative humidity (%)			Bright sunshine hours		
		Lower limit	Upper limit	Normal	Lower limit	Upper limit	Normal	Lower limit	Upper limit	Normal	Lower limit	Upper limit	Normal	Lower limit	Upper limit	Normal
Nursery	20	35.3	41.7	38.9	19.7	24.4	23.1	42.6	74.8	56.6	16.0	35.0	26.4	8.9	11.9	10.1
	21	36.2	42.8	39.5	20.2	24.9	23.7	41.6	73.3	55.3	16.6	31.0	26.5	9.7	12.0	10.0
	22	37.8	42.8	39.6	21.3	26.5	24.3	41.5	66.1	53.9	16.4	30.8	27.3	10.0	12.3	10.3
	23	38.1	42.4	39.5	22.8	26.3	25.4	44.3	68.2	58.3	16.3	36.1	31.1	9.5	12.3	10.0
	24	35.8	41.1	38.0	22.9	26.8	25.6	55.6	73.6	65.4	24.3	44.1	39.2	8.3	12.2	9.1
Average		36.6	42.2	39.1	21.4	25.8	24.4	45.1	71.2	57.9	17.9	35.4	30.1	9.3	12.1	9.9
Vegetative	25	36.0	41.5	37.5	23.9	29.1	26.4	52.9	74.4	68.1	27.8	48.1	43.6	7.2	12.2	8.7
	26	33.5	40.2	36.0	25.3	28.4	26.6	62.2	84.6	75.3	35.2	65.7	52.9	4.8	10.6	7.7
	27	31.6	37.5	35.2	24.8	26.4	26.3	70.0	91.4	79.7	42.4	75.1	58.0	4.5	9.7	7.4
	28	32.1	36.1	34.3	24.8	26.7	26.4	76.3	89.3	82.7	49.4	72.5	63.7	4.2	9.7	6.9
	29	31.9	36.2	33.9	25.1	26.9	26.4	81.7	90.4	84.5	52.4	77.8	66.0	4.6	10.0	6.6
	30	32.2	34.2	33.6	24.9	27.1	26.4	82.6	90.0	85.5	60.0	76.1	67.0	4.6	8.1	6.2
	31	31.4	35.1	33.2	25.1	27.1	25.9	83.0	91.6	86.6	60.1	79.5	69.3	3.8	8.6	6.2
	32	31.9	34.9	33.3	24.6	26.8	26.1	83.2	92.5	88.1	58.7	78.0	70.0	4.9	9.1	6.2
	33	32.3	34.6	33.5	24.1	26.5	25.7	78.5	94.7	85.4	56.0	75.1	65.4	5.6	9.8	7.0
	34	32.7	34.7	33.5	24.2	26.3	25.6	85.4	93.5	88.3	57.6	76.2	67.2	6.6	10.9	7.9
Average		32.6	36.5	34.4	24.7	27.1	26.2	75.6	89.2	82.4	50.0	72.4	62.3	5.1	9.9	7.1
Reproductive	35	32.1	35.4	33.5	23.1	25.7	25.1	83.3	93.7	88.2	51.5	73.5	65.6	5.8	11.5	7.8
	36	32.0	35.5	33.3	22.2	25.7	24.3	83.1	94.2	88.6	47.0	75.8	64.1	6.6	10.8	8.2
	37	31.7	35.0	33.3	21.6	24.1	23.5	82.4	94.3	88.6	48.6	68.9	60.6	6.9	11.4	8.6
	38	32.0	35.1	33.4	19.9	23.5	22.6	81.4	92.9	89.0	44.0	61.7	55.4	8.1	10.8	8.8
	39	31.0	34.7	33.2	18.7	22.6	21.2	79.7	94.1	87.9	37.6	65.1	49.4	7.8	10.8	9.2
	40	32.3	34.4	33.3	17.2	20.6	19.7	81.2	92.5	87.6	31.4	49.9	43.0	9.0	11.4	9.2
Average		31.9	35.0	33.3	20.5	23.7	22.7	81.9	93.6	88.3	43.4	65.8	56.4	7.4	11.1	8.6

respectively, (Table 1). The lower and upper limit of optimum morning /evening relative humidity varied between 41.5-55.6 and 66.1-74.8% / 16.0-24.3 and 30.8-44.1%, respectively.

Vegetative stage (25-34 SMW): The average optimum range for morning and evening relative humidity varied between 75.6-89.2 and 50.0-72.4%, respectively. Quite similar to our findings Rathnayake *et al*. (2016) reported that optimum relative humidity for rice lies between 60-80%.

Reproductive stage (35-40 SMW): The average optimum range for morning and evening relative humidity varied between 81.9-93.6 and 43.4-65.8%, respectively. The lower and upper limit of optimum morning /evening relative humidity varied between 79.7-83.3 / 31.4-51.5% and 92.5-94.3 / 49.9-75.8%, respectively.

Similar to our results Abeysiriwardena *et al*. (2002) found that average relative humidity of 85-90% coupled with a day/night temperature of 35/30 °C during heading stage induces almost complete grain sterility in rice thus leading to reduced productivity. During vegetative stage, rice requires 80-85% relative humidity (Sridevi and Chellamuthu, 2015). If the relative humidity is below 40 per cent, flowering is inhibited (Vijayakumar, 1996). The minimum 40% relative humidity is required for flowering of rice and the optimum for flowering lies between 70-80% (Sridevi and Chellamuthu, 2015).

Optimum range of sunshine hours/day for high productivity of rice

Nursery stage (20-24 SMW): The average optimum range for sunshine hours/day varied between 9.3-12.1 hours/day, respectively (Table 1). The lower and upper limit of optimum range of sunshine varied between 8.3-10.0 and 11.9-12.3 hours/day, respectively.

Vegetative stage (25-34 SMW): The average optimum range for sunshine hours/day varied between 8.1-9.9 hours/day, respectively (Table 1). The lower and upper limit of optimum range of sunshine varied between 3.8-7.2 and 8.1-12.2 hours/day, respectively.

Reproductive stage (35-40 SMW): The average optimum range for sunshine hours/day varied between 7.4-11.1 hours/day, respectively (Table 1). The lower and upper limit of optimum range of sunshine varied between 5.8-9.0 and 10.8-11.5 hours/day, respectively.

Validation of optimum ranges of weather parameters for higher productivity

The optimum ranges of weather parameters for higher productivity of rice were validated using the actual weather and Ludhiana district average rice productivity of two low (2014 and 2015) and two high yield (2017 and 2018) year.

Low rice productivity years (2014 and 2015)

The actual rice productivity at Ludhiana during the year 2014 and 2015 were 4424 and 4354 kg ha^{-1}, respectively, as compared to last 10 years (2009-2018) average of 4531 kg ha^{-1}.

In the year 2014, the weekly average maximum temperature (Fig. 2) was higher than the optimum range during 23 and 28th SMW by 2.1 and 2.6 ^{o}C, respectively. While the weekly average maximum temperature during 2014 was lower than optimum range during 36th SMW by 1.2 ^{o}C. In the year 2015, weekly average maximum temperature was higher than the optimum range during 37th SMW by 0.3 ^{o}C. The weekly average maximum temperature during 2015 was lower than optimum range during 28 and 38th SMW by 1.0 and 1.1 ^{o}C, respectively.

In the year 2014, the weekly average minimum temperature (Fig. 2) was higher than the optimum range during 24, 27, 28, 29, 30, 31, 32, 33, 34, 38, 39 and 40th SMW by 4.6, 2.4, 4.9, 2.7, 2.3, 2.5, 2.7, 2.8, 2.8, 4.9, 4.8 and 7.7 °C, respectively. In the year 2015, weekly average minimum temperature was higher than the optimum range during 21, 27, 29, 30, 32, 35, 37 and 38th SMW by 0.7, 1.3, 0.6, 0.7, 0.1, 1.5, 1.1 and 0.2 °C. While the weekly average minimum temperature during 2014 and 2015 was never below than the optimum range.

In the year 2014, the weekly average morning relative humidity (Fig. 2) was lower than the optimum range during 23, 28, 29 and 34th SMW by 3.1, 6.0, 4.7 and 5.4 per cent, respectively. In the year 2015, weekly average morning relative humidity was lower than the optimum range during 21, 30 and

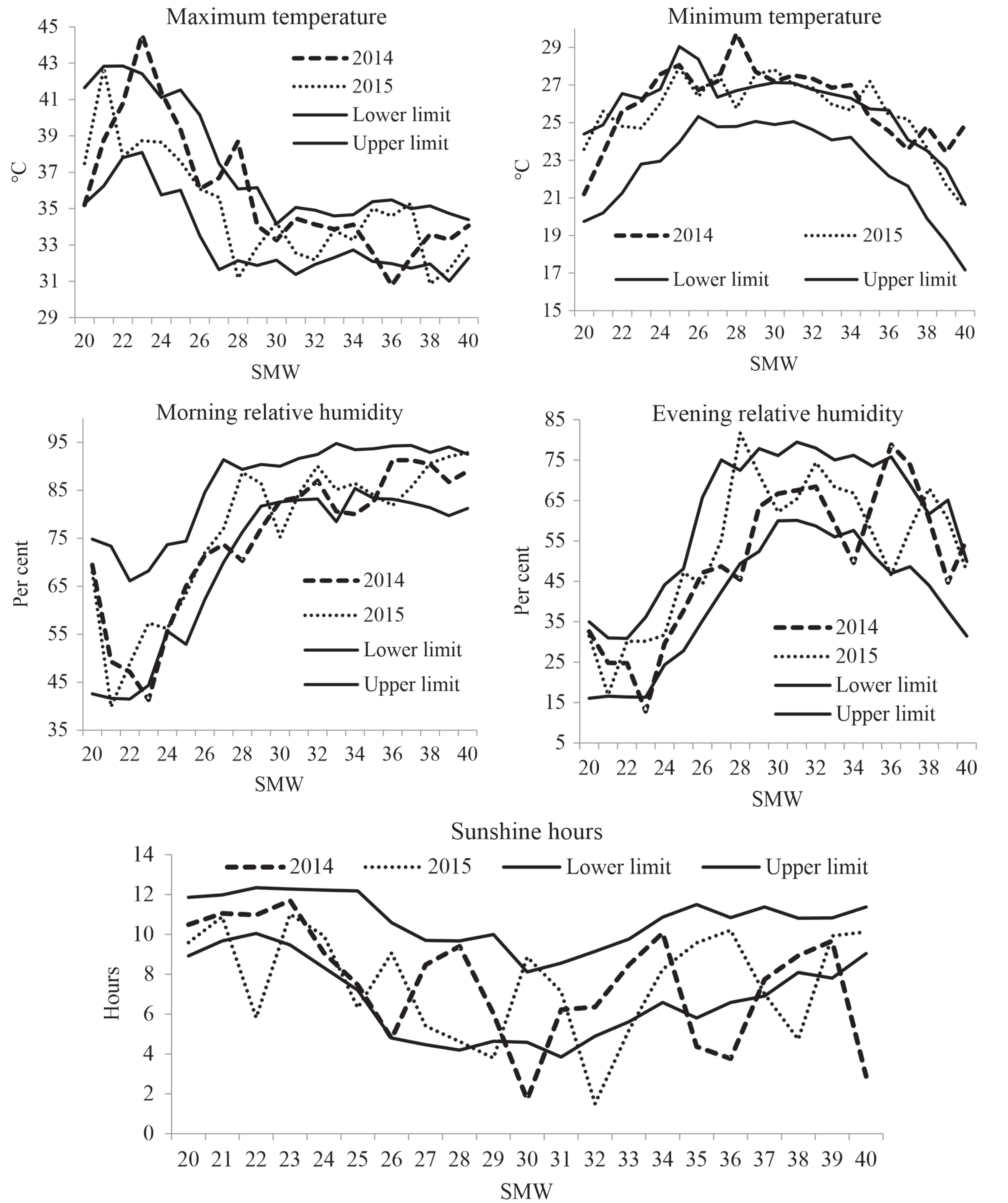

Fig. 2. Comparison of the actual weather parameters with the optimum range of weather parameters during low yield years (2014 and 2015)

36th SMW by 1.8, 7.3 and 1.3 per cent, respectively. The weekly average evening relative humidity during 2014 and 2015 was never higher than the optimum range.

In the year 2014, the weekly average evening relative humidity (Fig. 2) was higher than the optimum range during 36, 37 and 40th SMW by 3.0, 5.0 and 5.7 per cent, respectively. While, the weekly average evening relative humidity during 2014 was lower than the optimum range during 23, 28 and 34th SMW by 3.4, 4.0 and 8.1 per cent, respectively. In the year 2015, weekly average evening relative humidity was higher than the optimum range during 28 and 38th SMW by 9.2 and 6.3 per cent. The weekly average evening relative humidity during 2015 was never lower than the optimum range.

In the year 2014, the weekly average bright sunshine hours/day (Fig. 2) was lower than the optimum range during 30, 35, 36 and 40th SMW by 2.9, 1.4, 2.8 and 6.2 hours/day, respectively. In the year 2015, weekly average bright sunshine hours was lower than the optimum range during 22, 25, 29, 32, 33 and 38th SMW by 4.2, 0.9, 0.8, 3.4, 0.4 and 3.4 hours/day, respectively. The weekly average bright sunshine hours during 2014 and 2015 was never higher than the optimum range.

High rice productivity years (2017 and 2018)

The actual rice productivity at Ludhiana during the year 2017 and 2018 were 4815 and 4743 kg ha^{-1}, respectively, as compared to last 10 years (2009-2018) average of 4531 kg ha^{-1}.

In the year 2017, the weekly average maximum temperature (Fig. 3) was higher than the optimum range during 33 and 40th SMW by 0.4 and 0.6 °C, respectively. While the weekly average maximum temperature during 2018 was lower than optimum range during 38 and 39th SMW by 0.9 and 1.1 °C. In the year 2018, weekly average maximum temperature was never higher than the optimum range.

In the year 2017, the weekly average minimum temperature (Fig. 3) was higher than the optimum range during 20, 21, 23, 28, 29, 30, 31, 32, 33, 37, 39 and 40th SMW by 1.3, 1.5, 1.0, 1.6, 1.6, 0.6, 0.1, 1.2, 1.1, 0.4, 0.7 and 0.4 °C, respectively. In the year 2018, weekly average minimum temperature was higher than the optimum range during 22, 23, 28, 31, 33, 34, 35, 36 and 37th SMW by 1.4, 0.9, 1.4, 0.5, 0.3, 1.0, 1.8, 0.4, and 1.1 °C, respectively. While the weekly average minimum temperature during 2014 and 2015 was never below than the optimum range.

In the year 2017, the weekly average evening relative humidity (Fig. 3) was lower than the optimum range during 24, 28, 29, 30, 32, 34 and 36th SMW by 2.6, 2.3, 2.7, 3.6, 1.2, 0.4 and 2.1 per cent, respectively. In the year 2017, the weekly average evening relative humidity was higher than the optimum range during 25th SMW by 0.6 per cent. In the year 2018, weekly average morning relative humidity was lower than the optimum range during 21, 31 and 34th SMW by 8.6, 3.0 and 2.4 per cent, respectively. The weekly average evening relative humidity during 2018 was never higher than the optimum range.

In the year 2017, the weekly average morning relative humidity (Fig. 3) was higher than the optimum range during 21 and 22th SMW by 1.0 and 3.2 per cent, respectively. While, the weekly average morning relative humidity during 2017 was never lower than the optimum range. In the year 2018, weekly average evening relative humidity was higher than the optimum range during 23th SMW by 3.9 per cent. The weekly average morning relative humidity during 2018 was lower than the optimum range during 21 and 31st SMW by 7.6 and 2.1 per cent.

In the year 2017, the weekly average bright sunshine hours/day (Fig. 3) was lower than the optimum range during 21, 23, 31 and 34th SMW by 0.5, 0.9, 0.2 and 1.0 hours/day, respectively. In the year 2018, weekly average bright sunshine hours was lower than the optimum range during 20, 22, 23, 24, 29, 30, 33, 34, 35, 36 and 38th SMW by 2.7, 2.3, 2.0, 3.1, 0.6, 0.5, 1.3, 0.9, 0.9, 1.3 and 0.5 hours, respectively. The weekly average bright sunshine hours during 2017 and 2018 was never higher than the optimum range.

During low yield years (2014 and 2015) significant deviation of maximum temperature (2014), minimum temperature (2014 and 2015) and sunshine hours (2014 and 2015) form the optimum range could be the reason for low productivity of rice. However, slight deviation in minimum temperature (2017and 2018) could not negatively affected the productivity during high yield years (2017 and 2018) due to sufficient sunshine. Although during 2018 sunshine hours were less than the lower limit of the range during nursery stage and slightly lower than optimum range during end of vegetative and start of reproductive stage but could not affect the productivity negatively. The reason might be that

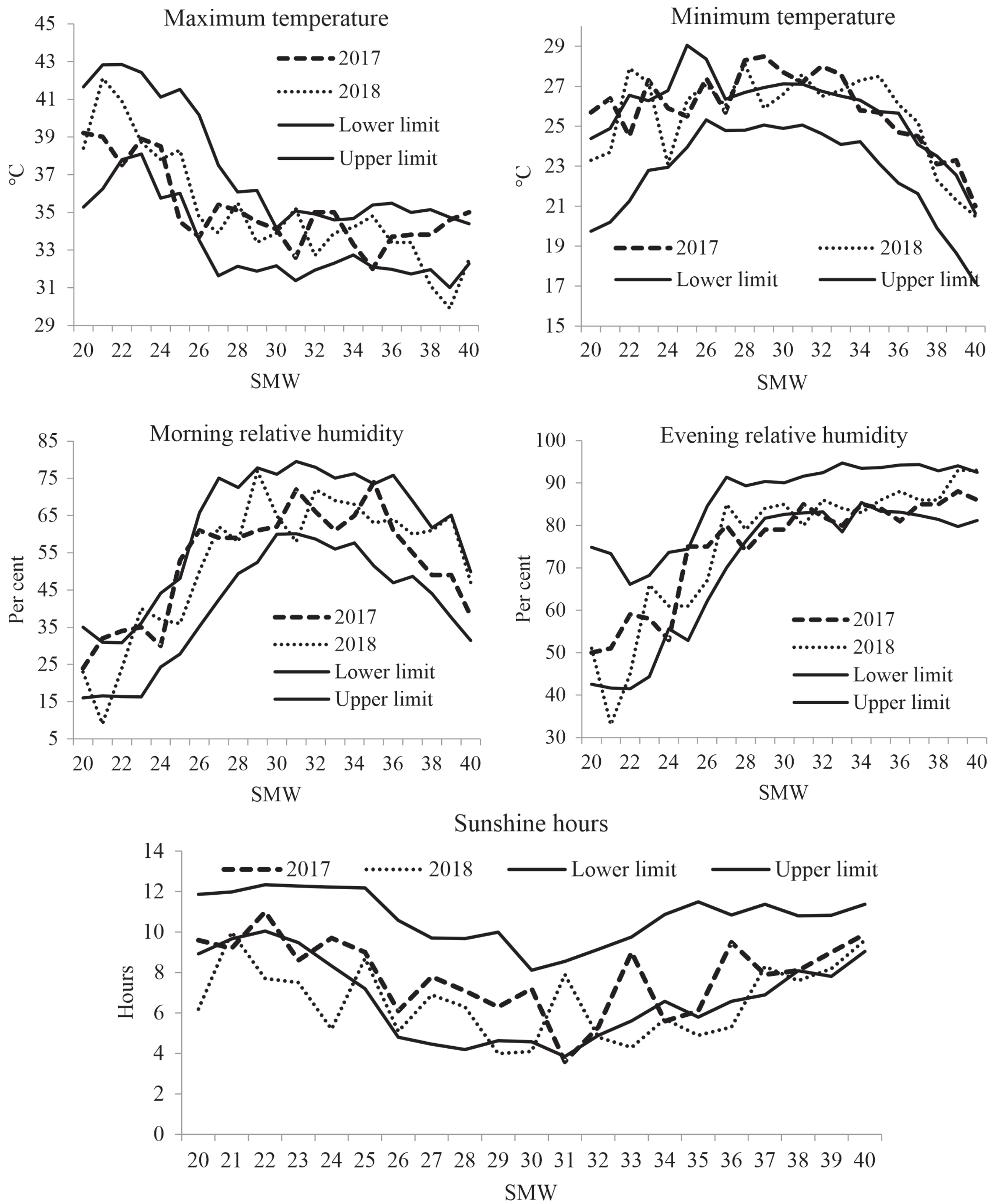

Fig. 3. Comparison of the actual weather parameters with the optimum range of weather parameters during high yield years (2017 and 2018)

nursery stage might not be that important in relation to sunshine hours and secondly during end of vegetative and start of reproductive stage (2018) the magnitude of reduction was very less, therefore it does not affect the yield significantly.

Conclusions

The present study was aimed to determine the optimum ranges of various weather parameters for high productivity of rice at Ludhiana using the methodology of detrending (Gommes and Hoefsloot, 2017) of the long term crop productivity data to separate the contribution of technological advancement from that of the weather. The ranges were calculated from 20th to 40th standard meteorological week (SMW) corresponding to a period ranging from nursery sowing to harvesting of rice crop. The results showed that at Ludhiana for high rice productivity during nursery stage (20-24 SMW) the optimum average range for maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and bright sunshine hours are 36.6-42.2 °C, 21.4-25.8 °C, 45.1-71.2%, 17.9-35.4% and 9.3-12.1 hours/day, respectively. The optimum average range for maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and bright sunshine hours during vegetative stage are 32.6-36.5 °C, 24.7-27.1 °C, 75.6-89.2%, 50.0-72.4% and 8.1-9.9 hours/day, respectively. The optimum average range for maximum temperature, minimum temperature, morning relative humidity, evening relative humidity and bright sunshine hours during reproductive stage are 31.9-35.0 °C, 20.5-23.7 °C, 81.9-93.6%, 43.4-65.8% and 7.4-11.1 hours/day, respectively.

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