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Short Communication

The role of meteorological parameters in determining yield of rice cultivated under flooded transplanted conditions in Ludhiana district - A case study

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Rice is a unique food crop by virtue of its extent and adaptability to wider range of edaphic, climatic and cultural conditions. About 90 per cent of the rice production takes place in the tropical/sub-tropical Asia where 60 per cent of the world population lives (Anonymous, 2013). In crop production climate is the least manageable part of environmental resources, yet a better understanding these parameters and their interactions with agriculture can help boost crop productivity (Kumari *et al*., 2017). The detailed knowledge of these crop-weather relationships can help derive complex varieties that give appropriate weight to different factors for correlation with yield in naturally varying climates, and use them to predict yield from meteorological records. Keeping this in view, an analytical study was carried out to critically examine the role of meteorological parameters at different stages of rice crop in determining its yield at Ludhiana during recent one decade (2009-19).

The data on area and yield for rice crop during recent decade (2009-2019) for Ludhiana was taken from statistical abstracts. The daily meteorological data (temperature, rainfall and sunshine hours) for the years 2009 to 2019 was taken from the Agrometeorological observatory, Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University Ludhiana. The meteorological data was analysed on daily, weekly (Standard Meteorological Week –SMW) and crop stage wise basis by identifying the low yield and high yield years over the recent decade. The basic assumption made was that during recent decade the contribution of agro-technological advancement would be similar and any abrupt deviation (positive or negative) in yield of rice would be primarily due to meteorological parameters.

The rice crop stage wise (Vegetative : 26 to 33 SMW, flowering : 34 to 36 SMW and grain filling stage : 37 to 43 SMW) comparison and their deviations from long term normals computed from 1970 to 2015 (Prabhjyot-Kaur *et al.* 2016) for meteorological parameters were made on daily (25 June-28 October) and weekly (26 to 43 SMW) basis for high and low yield years. A correlation analysis of the meteorological parameters during the three main crop growth stages of rice with the district yield was done to evaluate their effects.

Changes in area and yield of rice

Over the recent decade the area under rice crop increased from 2,54,000 ha (2009) to 2,59,000 ha (2019) while the yield varied from a low of 4257 kg ha^{-1} (2012) to a high yield of 4815 kg ha^{-1} (2007) (Fig.1). The area under rice crop increased during year 2010, 2017, 2019 and decreased during 2009, 2018 and remained same during remaining six years. The average yield of rice from crop year 2009 to 2019 was 4523.5kg ha^{-1}. Assuming the influence of technological advancement to be nearly nil over recent decade, then the yield of rice was above average (4523.5 kg ha^{-1}) during four years while it was highest (+6.4% above average) during 2017. During remaining six years the yield was below average and the lowest yield was observed during 2012 i.e., -5.9% less than average yield.

Crop stage wise comparison of rice yield with weather parameters

The rice crop stage wise i.e vegetative (VG), flowering (FL) and grain filling (GF) stage comparison of weekly weather parameters with normal values was made for six low yield and one high yield year. During the high yield year 2017, the weekly maximum temperature (Tmax) remained above normal during VG stage (26 to 33 SMW: 32.8 to 35.8°C) and GF stage (37 to 43 SMW: 31.4 to 35.0 °C), while it remained close to normal during FL stage (34 to 36 SMW: 32.0 to 33.4 °C). However, during low rice yield years (2011, 2012, 2014, 2015, 2018 and 2019) the weekly Tmax remained fluctuating during VG and FL stages and then remained

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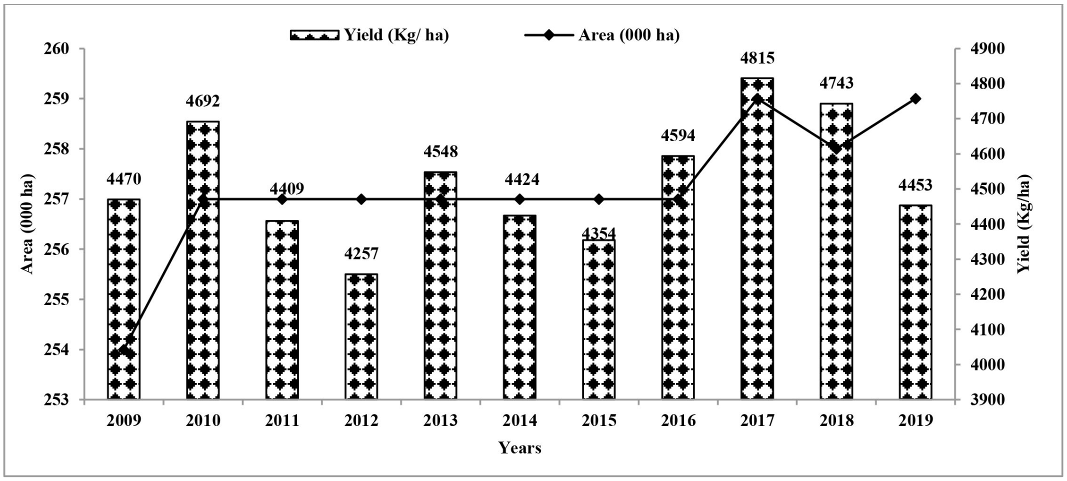

Fig. 1: Changes in the area and yield of rice over the past decade at Ludhiana (2009-2019)

Table 1: Stage wise correlation analysis of rice yield (2009-2019) with meteorological parameters

Crop growth phase	Tmax (°C)	Tmin (°C)	Rainfall (mm)	Sunshine hours (hrs)
Vegetative stage (26 SMW- 33 SMW)	-0.23	0.03	-0.01	-0.13
Flowering Stage (34 SMW - 36 SMW)	0.15	-0.03	-0.02	0.06
Grain filling Stage (37 SMW - 43 SMW)	0.26	0.14	-0.16	-0.21

Table 2: Stage wise linear regression analysis of rice yield (2009-2019) with weather parameters

Weather parameters	Statistics	Stages		
		Vegetative	Flowering	Grain filling
Maximum temperature (Tmax)	Intercept	6154.95	3502.95	2692.32
	Tmax (°C)	-47.55	30.78	56.79
	Multiple R	0.23	0.15	0.26
	R^2	0.05	0.02	0.07
	Adjusted R^2	-0.05	-0.09	-0.04
	Standard error	176.98	179.85	175.69
	Significance F	0.50	0.66	0.44
Minimum temperature (Tmin)	Intercept	4184.22	4704.64	3938.46
	Tmin (°C)	12.54	-6.99	28.17
	Multiple R	0.03	0.03	0.14
	R^2	0.00	0.00	0.02
	Adjusted R^2	-0.11	-0.11	-0.09
	Standard error	181.78	181.80	180.14
	Significance F	0.93	0.93	0.69
Rainfall (RF)	Intercept	4529.00	4530.05	4566.26
	RF (mm)	-0.01	-0.09	-0.46
	Multiple R	0.01	0.02	0.16
	R^2	0.00	0.00	0.03
	Adjusted R^2	-0.11	-0.11	-0.08
	Standard error	181.86	181.84	179.59
	Significance F	0.97	0.96	0.64
Sunshine hours (SSH)	Intercept	4697.61	4482.51	4794.07
	SSH (hrs)	-0.53	0.30	-0.74
	Multiple R	0.13	0.06	0.21
	R^2	0.02	0.00	0.04
	Adjusted R^2	-0.09	-0.11	-0.06
	Standard error	180.40	181.53	177.87
	Significance F	0.71	0.86	0.54

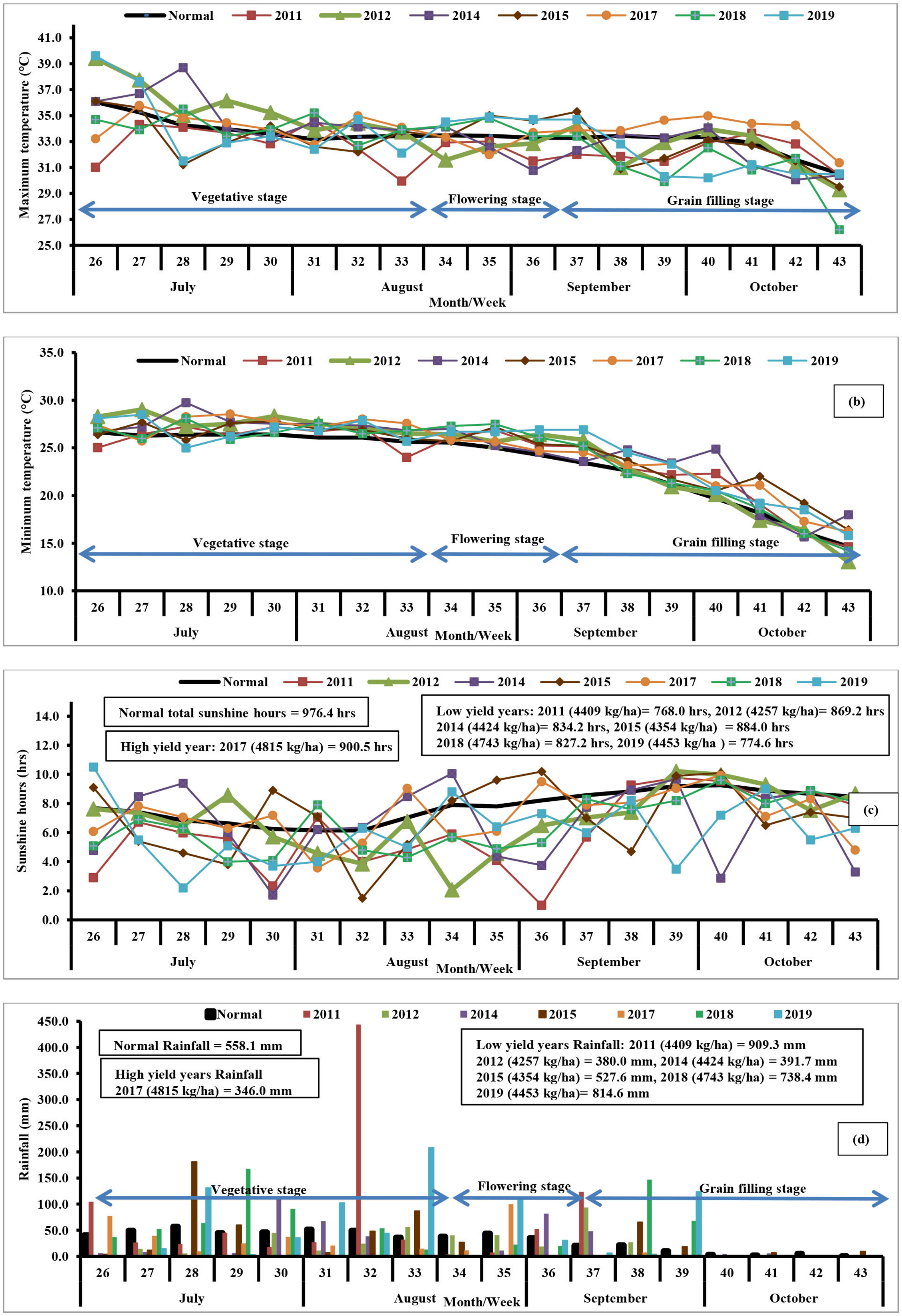

Fig. 2: Comparison of stage wise weekly maximum temperature (a) and minimum temperature (b), sunshine hours (c) and rainfall (d) with normal for low and high yield years of rice in Ludhiana district

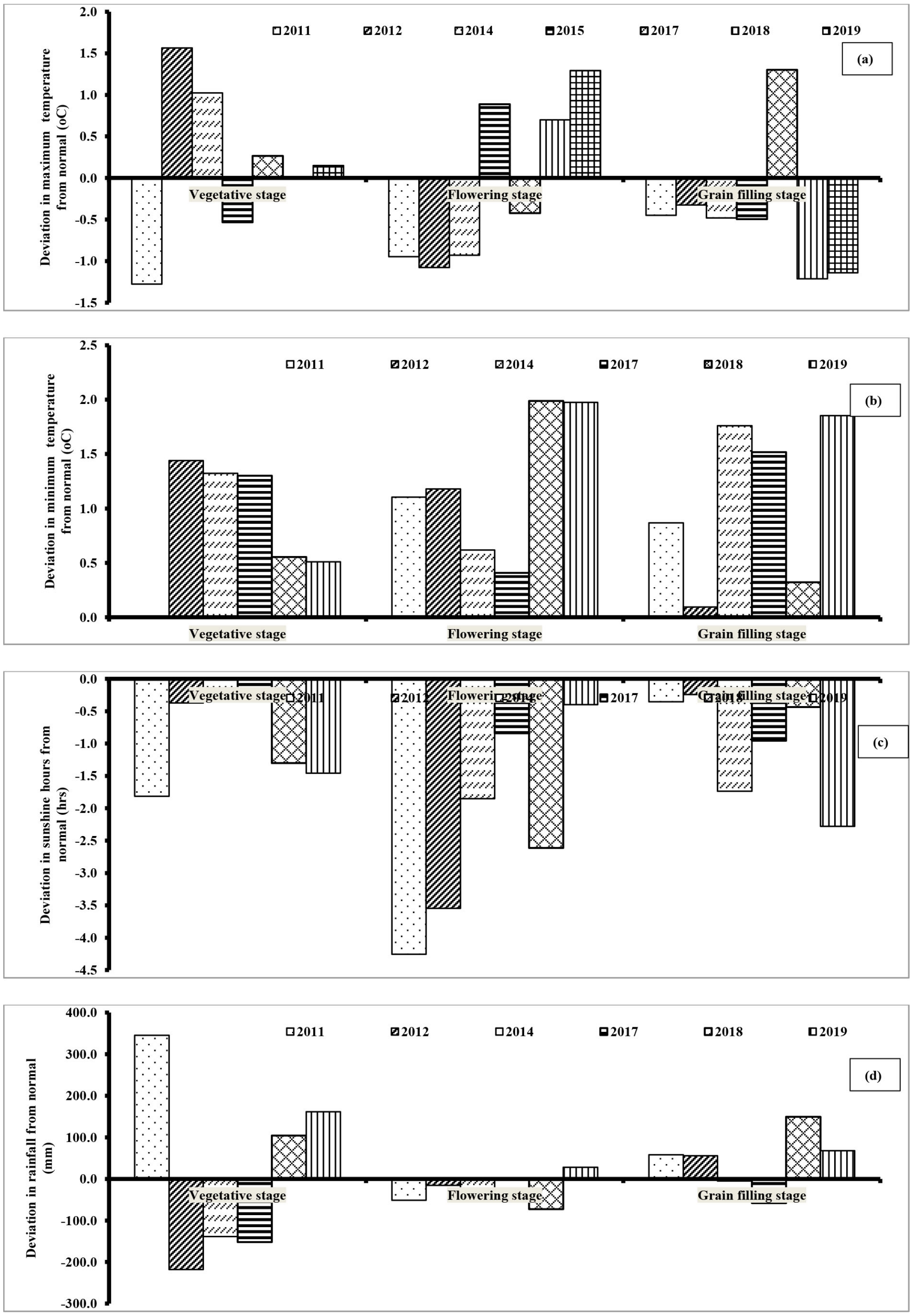

Fig. 3: Deviation of maximum temperature (a), minimum temperature (b), sunshine hours (c) and rainfall (d) from normal at different growth stages of rice crop for high and low yield years in Ludhiana district

below normal during GF stage (37 to 43 SMW : 26.2 to 34.0 °C) (Fig 2a). The weekly minimum temperature (Tmin) remained above normal during both low and high yield years (Fig. 2b). The rate of tillering tends to increase as the temperature increases (Lalitha *et al.,* 2000; Sridevi and Challamuthu, 2015) but temperatures of >35ºC during the reproductive stages reduces rice production as the it causes low seed setting and low yield.

The normal SShr during VG stage are 377 hr and the high yield year (2017) recorded 366 hr while all six low yield years experienced more cloudy weather and hence lesser SShr (Fig. 2c). The FL stage of rice is experienced during peak monsoon season months (mid August to 1st week September) with a normal SShr of 166 hr. During all the years under study the total SShr remained below than normal except during 2015 (196 hr). The normal SShr during GF stage are 433 hr and due to cloudy sky conditions they were below normal during all the years. The total SShr recorded during high yield year 2017 was 900 hr against a normal of 976

Table 3 : A summation of crop stage wise meteorological parameters determining the yield of rice in Ludhiana district

Meteorological parameter	Vegetative Stage (26-33 SMW)			Flowering Stage (34-36 SMW)			Grain filling Stage (37-43 SMW)		
	Normal	Highest yield year 2017 (4815 kg ha^{-1})	Lowest yield year 2012 (4257 kg ha^{-1})	Normal	Highest yield year 2017 (4815 kg ha^{-1})	Lowest yield year 2012 (4257 kg ha^{-1})	Normal	Highest yield year 2017 (4815 kg ha^{-1})	Lowest yield year 2012 (4257 kg ha^{-1})
Maximum temperature (°C)	34.1	34.4	35.7	33.4	33.0	32.3	32.6	33.9	32.3
Minimum temperature (°C)	26.3	27.6	27.7	25.0	25.4	26.1	19.4	20.9	20.3
Rainfall (mm)	377.0	225.0	159.0	115.0	114.0	100.0	66.0	7.0	122.0
Sunshine hour (hr)	377.0	366.0	357.0	166.0	149.0	92.0	433.0	386.0	421.0

hr. But all the six low yield years recorded lesser total SShr (2011: 768 hr, 2012: 869 hr, 2014: 834 hr, 2015: 884 hr, 2018: 827 hr and 2019: 775 hr).

In irrigated plains of Punjab due to assured irrigation facilities the distribution and timing of RF are more important than its amount. The incidence of one heavy RF event at a critical growth stages like FL and GF can adversely affect the yield of rice. The normal RF at Ludhiana during vegetative stage is 377mm and it was below normal during the high yield year 2017 (225 mm) and two low yield years (2012 :159 mm and 2014 :238 mm) (Fig 2d). In rest four low yield years it was above normal (2011: 722 mm, 2015: 399 mm, 2018: 481 mm and 2019: 538 mm). During FL stage normal rainfall at Ludhiana is 115mm and it was near normal during the high yield year 2017 (114 mm). It was below normal during four low yield years (2011: 64 mm, 2012: 100 mm, 2014: 93 mm and 2018: 43 mm) and above normal during 2019: 143 mm). Girish and Hittalmani (2004) found that moisture stress 10 days after 50 per cent flowering significantly reduced panicle and test weight, total and fertile spikelets per panicle, spikelet density and significantly increased sterile spikelets per panicle.

Deviation of weather parameters from normal during high and low rice yield years

A normal or slightly above normal Tmax (0.3 to 1.3°C) are conducive for good growth and yield of rice especially during early VG and GF stage (Fig 3a). During the VG stage of rice the Tmax was ±0.3°C from normal during high yield year (2017), remained below normal by nearly 0.5 to 1.3°C during low yield year (2011 and 2015) and above normal by 1.0 to 1.6°C during low yield years (2012 and 2014). At FL stage, during low yield years it remained below normal by 0.9 to 1.1°C (2011, 2012 and 2014) and above normal by 0.7 to 1.3°C (2015, 2018 and 2019), while it remained 0.4 °C below normal during high yield year 2017. At GF stage, during all six low yield years the Tmax remained below normal by 0.3 to 1.2°C and was above normal by nearly 1.3 °C during high yield year (2017).

The Tmin remained above normal during all the low and high rice yield years (Fig 3b). The high yield year (2017) had a good combination of above normal Tmin, i.e., +1.3°C during VG stage, +0.4°C during FL stage and +1.5 °C during GF stage. The Tmin at VG stage, during low yield years 2012, 2014, 2015, 2018 and 2019 remained above normal by 1.4, 1.3, 0.6, 0.6 and 0.5 °C, respectively; at FL stage, during 2011, 2012, 2014, 2015, 2018 and 2019 remained above normal by 0.6 to 2.0°C and at GF stage, during 2011, 2012, 2014, 2015, 2018 and 2019 remained above normal by 0.9, 0.1, 1.8, 1.7, 0.3 and 1.9 °C, respectively. Prabhjyot-Kaur and Bala (2014) reported that optimum Tmax/Tmin for rice crop is 31–42°C/21–29°C during VG stage, 30–36°C/24–28°C during FL stage and 30–35°C/22–25°C during grain development stage in Punjab state.

The SShr remained below normal during all the low and high yield years at all stages (Fig 3c). The high yield year (2017) had SShr below normal deviation of 0.2, 0.8 and 1.0 hr during VG, FL and GF stage, respectively. During low yield years 2011, 2012, 2014, 2015, 2018 and 2019 the SShr remained below normal by 1.8, 0.4, 0.3, 1.0, 1.3 and 1.5 hr, respectively at VG stage, by 4.3, 3.5, 1.9, 2.6 and 0.4 hr, respectively at FL stage and by 0.4, 0.2, 1.7, 1.3, 0.4 and 2.3 hr, respectively during GF stage. Prabhjyot-Kaur *et al.* (2021) reported that the scarcity of SShr (cloudy weather) leads to reduction in solar radiation.

A combination of normal RF during VG and FL stage and below normal during GF stage (Fig 3d) is a precursor for high yield of rice. During 2017, a high yield year the RF was -152 mm (VG stage), -2 mm (FL stage) and -59 mm (GF stage) below normal RF. On the other hand, during the VG stage of low yield years 2011, 2015, 2018 and 2019, the RF was above normal by 345, 22, 104 and 161 mm, respectively and below normal by 218 and 139 mm during 2012 and 2014, respectively. During the FL stage of low yield years 2011, 2012, 2014, 2015, 2018 and 2019 the RF remained below normal by 52, 16, 22, 89, 73 and 28 mm, respectively. While during GF stage of low yield years 2011, 2012, 2015, 2018 and 2019 the RF remained above normal by 57, 56, 36, 149 and 68 mm, respectively.

Correlation of rice yield with meteorological parameters

The correlation analysis between grain yield of rice and meteorological parameters over the past decade (2009-2019) revealed that the VG stage was negatively correlated with Tmax (r = -0.23), RF (r = -0.01) and SShr (r = -0.13) while the Tmin was positively correlated (r = +0.03) (Table 1). Sridevi and Chellamuthu (2015) also reported similar relationship, i.e., cooler daytime temperature are conducive for rice crop. During flowering stage of rice crop the Tmax and SShr shows positive correlation i.e r = +0.15 and r = +0.06, respectively. The Tmin and RF showed negative correlation i.e = -0.03 and r = -0.02, respectively. This indicates that clear sky conditions with higher daytime and lower nighttime temperature are beneficial for the flowering stage of rice crop. These results are in concurrence with the findings of Chen *et al*., (2014) and Jain *et al*., (2019). The GF stage of rice revealed positive relationship of Tmax (r = +0.26) and Tmin (r = + 0.14) with grain yield and negative correlation with rainfall (r = -0.16) and SShr (r = -0.21). The analysis indicated that above normal or heavy rainfall at any stage (Vegetative, Flowering and GF) of rice crop adversely affect the grain yield. A negative relationship between rainfall and rice yield has been reported by Saseendran *et al*., (2000) and Nokkoul and Wichitparp, (2013).

Regression analysis of rice yield with meteorological parameters

Linear regression models were developed for predicting rice yield with meteorological parameters at different phenological stages (Table 2) using the observed data for recent decade (2009-19). Similar yield prediction models for rice crop were also developed by Chauhan *et al*., (2009) and Setiya and Nain, (2021). In linear regression, Tmax seems to be influencing negatively at VG and positively at FL and GF stages whereas Tmin positively at VG and GF stages but negatively at FL stage. Zhang *et al*., (2013) also observed reduction in yield due to increase in Tmin during reproductive growth stage. The effect of sunshine hours on grain yield was found to be positive at FL stage.

The analysis showed that over the past decade when highest yield (4815 kg ha^{-1}) of rice was recorded during crop year 2017 (Table 3), the Tmax remained 0.6 °C above normal (33.4 °C), Tmin remained 1.2°C above normal (23.4 °C), total SShr of 900.5 hour remained close to normal (976 hr) and the total RF of 346 mm was below normal (558 mm). During 2012 when the lowest yield (4257 kg ha^{-1}) of rice was recorded (Table 3), the Tmax remained 0.4 °C above normal (33.4 °C), Tmin also remained (0.9°C) above normal (23.4 °C) and total SShr of 869.2 hour were below normal (976 hr). Though the RF of 380 mm was below normal (558 mm), but 37 percent of this was received during first fortnight of September in form of heavy downpour were not favourable for rice crop. One common observation was that during all the six low yield years the total SShr were appreciably below normal i.e., cloudy sky conditions were observed and the total RF was much higher than normal especially during the GF stage of rice crop**.**

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