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Research Article

Weather-Based Thumb Rule Models for Prediction of Rice Yield in Punjab

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ABSTRACT

A study was conducted to evaluate the effect of abiotic stresses on rice (*Oryza sativa* L.) yield and formulate weather based Thumb Rule Models for predicting potential yield of rice in Punjab. The study was based upon collection and analysis of historical (1999-2009) weather and crop data from eight locations in Punjab. The weekly and monthly normals of meteorological parameters were computed from the daily data for these locations. These climatic normals were used for comparing the actual data to evaluate the effect of weather variables on yield of rice crop. Results indicated that during the period, rice yield increased by 21, 30, 32, 2, 31, 25 and 5% in Ballowal Saunkhri, Ludhiana, Bathinda, Jalandhar, Patiala, Faridkot and Abohar, respectively, although in Amritsar, 13% reduction in the yield was recorded. As the data suggested, heading and flowering stages happened to be the most critical. Meteorological data of the years with high rice yield were analyzed to work out the critical ranges of meteorological parameters for different growth stages. Weather based Thumb Rule Models using the weekly meteorological data were developed for predicting the potential yield of rice crop. These models can be used for agro-advisory services and for the prediction of potential crop yield at the selected locations in Punjab state.

Key words: Abiotic stress, Meteorological parameters, Potential yield, Rice, Punjab

Inroduction

Rice as staple food crop plays an important role in the Indian economy. India is world's second biggest rice producer country contributing 26% in world rice production. The geographical area of Punjab state is 1.53% of the country; however, it has contributed nearly 40-50% of rice towards central pool in last two decades (Anonymous, 2010a). In Punjab, it ranks second after wheat in terms of area, production and yield, occupying an area of 28.02 lakh hectare with production of 112.36 lakh tonnes and an average yield of 4.1 t ha^{-1} (Anonymous, 2010b).

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Deviation from essential requirements leads to changes in physiological processes in a crop at which it may experience stress. This state of the crop is referred to as 'crop stress'. There are two major categories of the stress, namely: (a) Controllable factors (Crop management practice, cultivar type, soil type, biotic stress due to pest and weed infestations etc), and (b) Uncontrollable factors (Abiotic factors, e.g., weather aberrations) (Orcutt and Nilsen, 2000). Climate is considered the major abiotic factor as the climate-induced variability in crop yield accounts for 67% while other factors including soil and nutrients management accounts for 33% of the productivity (Reddy and Reddy, 2007).

Temperature is the most important factor which influences the growth, yield and development of rice. According to Farrell *et al.* (2006), the flowering stage and to a lesser extent, booting stage in rice crop are the most susceptible stages of development to temperature stress. Pingping *et al.* (2009) found that under high temperature stress, pollen germination rate and pollen vitality decreased significantly causing reduction in yield. Chakrabarti *et al.* (2010) found that rise in temperature increased the pollen sterility and reduced the germination of pollen grains on the stigma. They also reported that non-basmati varieties were less affected by increase in temperature than basmati types. Prabhjyot-Kaur and Hundal (2010) reported that with an increase in temperature by 1-2 °C from normal, the simulated maximum leaf area index decreased by 3.5 to 9.2% and grain yield decreased by 2.8 to 9.6%. Correlation analysis using historical data suggested that rice grain yield declined by 10% for each 1°C increase in minimum temperature during growing season (Nie *et al.*, 2007).

Soil moisture stress from flowering to milk stage leads to highest reduction (75%) in grain yield than the water stress at other periods (Prasada Rao, 2008; Sarvestani *et al.*, 2008). A reduction in grain yield is largely resulted from the reduction in fertile panicle and also less filled-grain percentage. Water deficit during vegetative, flowering and grain filling stages reduced mean yield by 21, 50 and 21%, respectively on average in comparison to control. Rice is a short-day plant and it requires an optimum photoperiod of 10.0-10.5 h d^{-1} for normal flowering. Lesser sunshine hour has marginal effect on yield during vegetative stage but reduction in yield occurs during reproductive stage. Reduction in grain yield is due to the increased number of sterile spikelets (Reddy, 2004; Vijayalakshmi *et al.,* 2008; Das, 2010). During pollination, strong wind may induce sterility and increase the number of abortive endosperms. High wind speed during flowering may cause pollen dehydration and consequently leading to spikelet sterility (Prasada Rao, 2008). Keeping these in background, a study was conducted to evaluate the effect of weather induced abiotic stresses on yield of rice and to develop weather based 'Weekly Thumb Rule Models' for predicting the potential yield of rice crop in Punjab.

Materials and Methods

Daily weather data (maximum and minimum temperature, rainfall, sunshine hours and relative humidity) for Ludhiana, Amritsar and Patiala (1970-2009), Jalandhar (1971-2009), Ballowal Saunkhri (1984-2009), Bathinda (1977-2009), Faridkot (2000-2009) and Abohar (2004-2009) were used to compute the weekly and monthly climatic normals. Data on area, production and yield of rice were also collected for these selected locations (1999 to 2009) to find out the increase or decrease in area, production and yield over past eleven years.

Data on different phenological growth stages (Sowing, transplanting, tillering, heading, flowering, grain filling and physiological maturity) of rice were collected from the Annual report of the 'All India Coordinated Research Project on Agrometeorology' for formulating the 'Crop-Weather Calendar' for these locations.
The effect of inter- and intra-seasonal meteorological parameters on different growth stages and the final yield of rice were established as per three major categories (high, medium and low crop-yield year) by calculating the variabilities in meteorological parameters. Weekly and monthly deviations from the normal values during the rice season were calculated to identify the influence of meteorological parameters on the grain yield of rice. On the basis of critical limit of parameters, weather based weekly 'Thumb Rule Models' for predicting the potential yield of rice crop were developed.

Results and Discussion

Change in area, production and yield of rice in Punjab

Historical data revealed that during last 11 years, area, production and yield of rice in Punjab increased by 8, 29 and 20%, respectively. The location-wise analysis of historical yield data of

rice indicated that over the period, rice yield increased by 21, 30, 32, 2, 31, 25 and 5% in Ballowal Saunkhri, Ludhiana, Bathinda, Jalandhar, Patiala, Faridkot and Abohar, respectively while Amritsar recorded 13% reduction in yield (Table 1). Variation in yield would presumably be due to combination of variation in weather conditions.

Table 1. Area, production and yield of rice at eight locations in Punjab

Year	Ballowal	Amritsar	Jalandhar	Ludhiana	Patiala	Bathinda	Faridkot	Abohar
				Area ('000 ha)				
1999	61	318	133	237	251	99	90	280
2000	63	319	136	238	256	99	90	248
2001	60	319	132	235	251	82	70	230
2002	56	311	133	236	237	107	86	234
2003	58	326	138	241	246	105	84	244
2004	56	334	145	247	250	102	88	238
2005	61	179	151	250	238	95	86	236
2006	56	178	147	248	237	87	85	235
2007	56	178	149	250	234	86	87	243
2008	60	183	155	254	238	97	95	260
2009	70	185	161	257	240	104	98	262
Change (%)	15	-42	21	8	-4	5	9	-6
				Production ('000 tones)				
1999	178	988	464	856	815	342	305	982
2000	192	972	488	939	857	350	310	898
2001	171	958	445	916	908	307	268	864
2002	159	879	495	1020	818	367	280	824
2003	179	872	465	1047	950	419	308	903
2004	171	1034	538	1144	965	415	337	941
2005	182	520	526	1130	940	385	339	956
2006	157	538	514	1084	989	358	338	948
2007	185	546	554	1133	999	368	351	1010
2008	209	532	588	1135	1009	427	414	1051
2009	248	501	636	1206	1021	476	414	964
Change (%)	39	-49	37	41	25	39	36	-2
				Yield (kg ha^{-1})				
1999	2920	3108	3887	3611	3248	3453	3388	3509
2000	3047	3047	3588	3947	3348	3539	3446	3622
2001	2847	3003	3369	3897	3619	3742	3823	3755
2002	2838	2826	3721	4322	3453	3431	3256	3520
2003	3075	2675	3315	4342	3863	3985	3666	3700
2004	2952	3095	3711	4633	3854	4067	3830	3954
2005	2975	2907	3484	4521	3951	4057	3941	4049
2006	2795	2997	3494	4371	4174	4109	3978	4035
2007	3302	3064	3717	4532	4270	4275	4038	4157
2008	3480	2907	3797	4470	4240	4398	4357	4043
2009	3536	2708	3948	4692	4255	4575	4219	3680
Change (%)	21	-13	2	30	31	32	25	5

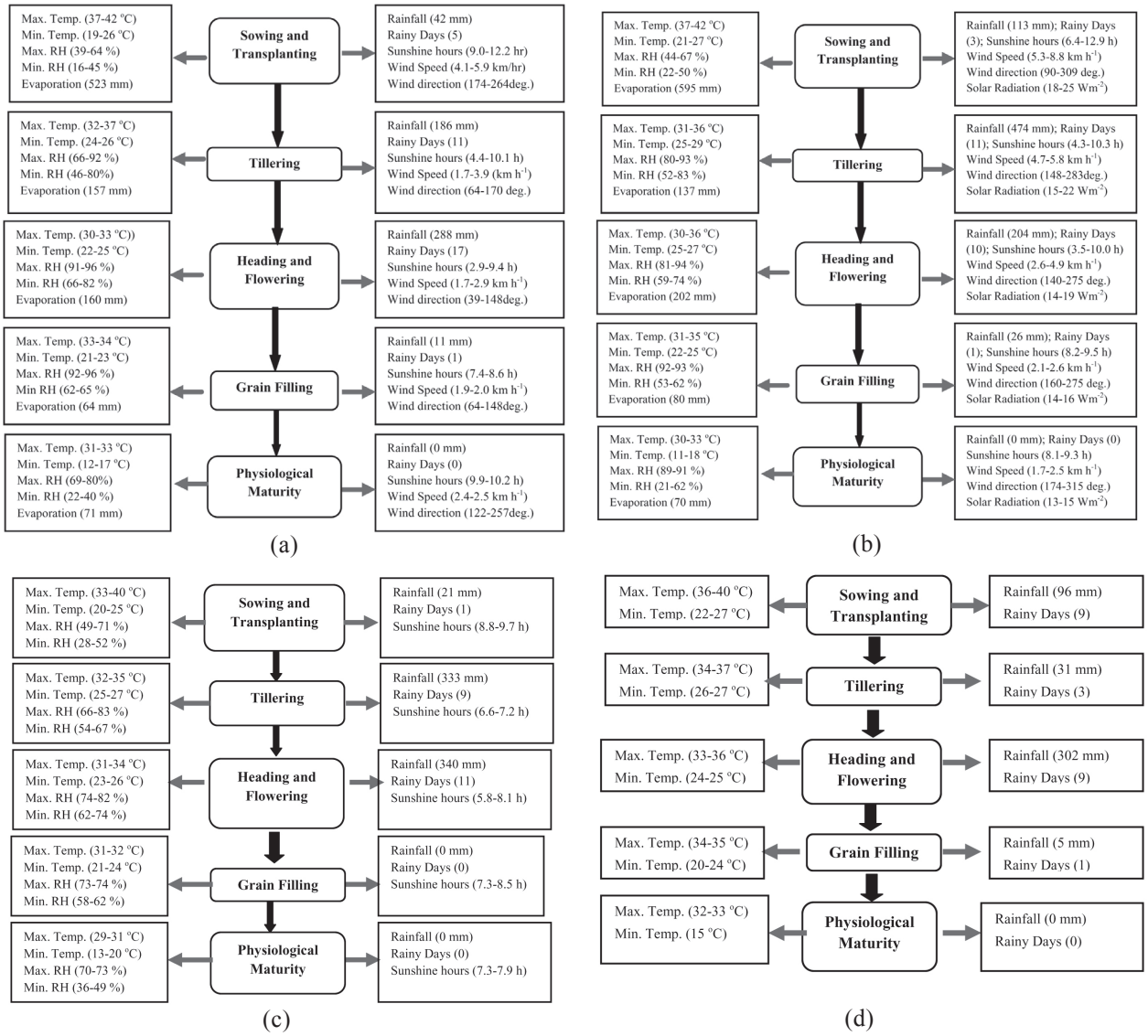
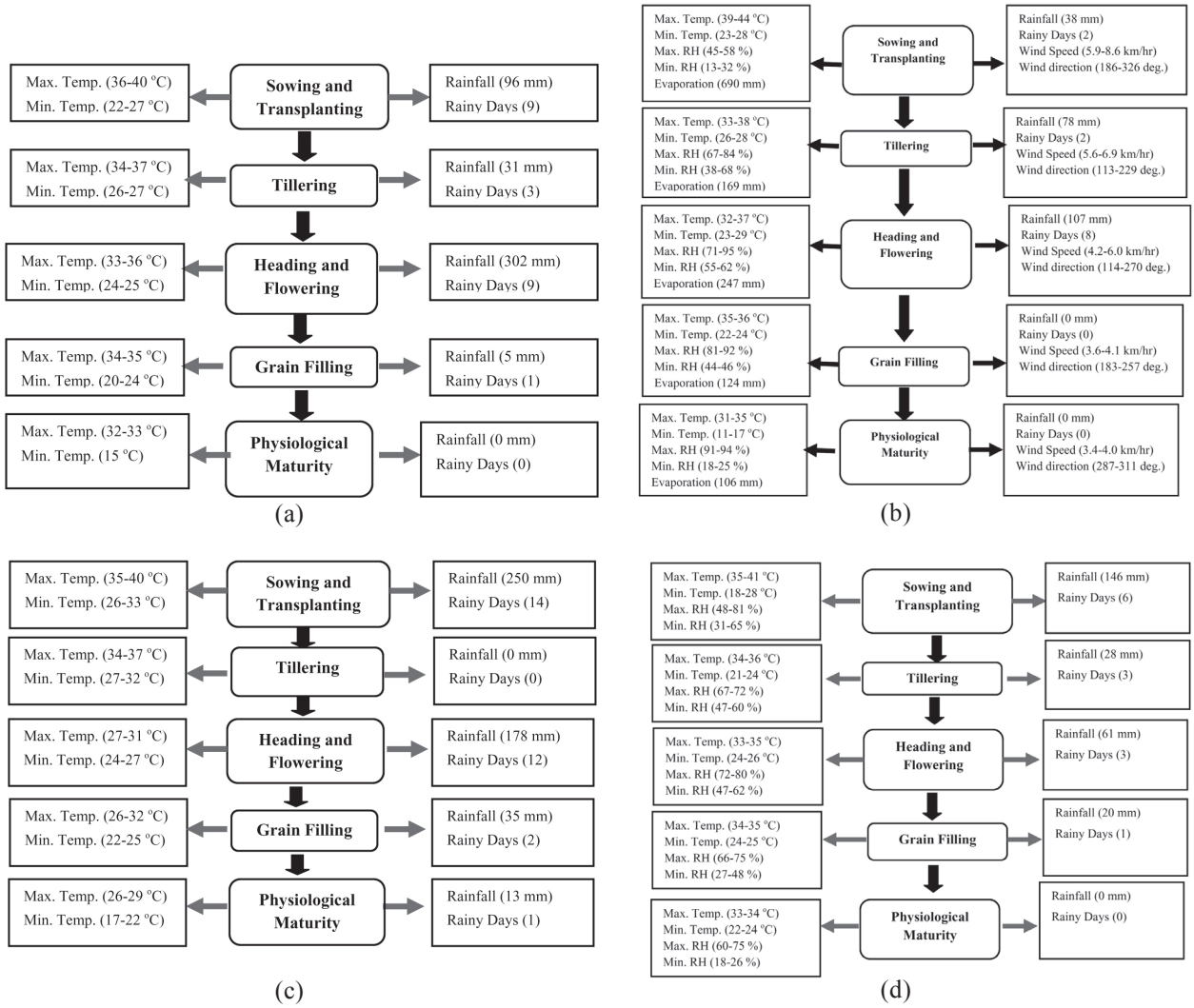


Fig. 1. Weekly Thumb Rule Model for prediction of rice yield at Ballowal Saunkhri (a), Ludhiana (b), Jalandhar (c) and Patiala (d)

Crop stage wise weather based 'Weekly Thumb Rule Models'

On the basis of critical limits of meteorological parameters during different growth stages, weather based 'Weekly Thumb Rules Models' were developed (Fig 1-8) for predicting yield of rice at the selected locations. Ranges of meteorological parameters favorable for rice crop in these selected locations are:

1. **Sowing and transplanting period:** Maximum (35-42°C) and minimum (21-27°C) temperature, maximum (40-60%) and minimum (25-45%) relative humidity, rainfall (100 mm), rainy days (5-10), evaporation (550-600 mm), sunshine hour (7-12 h), wind speed (5-7 km h^{-1}) and wind direction (90-320 degree).
2. **Tillering stage:** Maximum and minimum temperature ranges of 32-36 and 25-29°C, maximum and minimum relative humidity of 65-80 and 50-65%, rainfall (150-200mm), rainy days (8-10), evaporation (140-160 mm), sunshine hour (5-10 h), wind speed (2-6 km h^{-1}) and wind direction (90-270 degree).



3. **Heading and flowering stage:** Maximum temperature (30-35°C), Minimum temperature (25-27°C), relative humidity (max: 80-90%; min: 50-70%), rainfall (150-250 mm), rainy days (8-10), evaporation (160-200 mm), sunshine hour (4-9 h), wind speed (2-6 km h^{-1}) and wind direction (90-270 degree).
4. **Grain filling stage:** Temperature (31-35°C and 22-25°C as max and min), relative humidity (70-85%, max; 40-60%, min), rainfall (30mm), rainy days < 2, evaporation (40-60 mm), sunshine hour (7-9 h), wind speed (2-3 km h^{-1}) and wind direction (180-270 degree).
5. **Physiological maturity stage:** Maximum and mimimum temperature of 30-33 and 12-18°C, respectively; maximum (60-80%), minimum (20-40%) relative humidity, rainfall (0-10 mm), rainy days (<2), evaporation (50-70mm), sunshine hour (8-9 h), wind speed (1.5-2.5 km h^{-1}) and wind direction (120-300 degree).

Rice crop is a water-loving *kharif* season crop and requires relatively high temperature and rainfall for the optimum growth and development. Results indicated that temperature above normal in the months of August and September for a continuous period could be harmful as it cause spikelet sterility. Heading and flowering stage of rice are very critical stages and any sudden change in weather may adversely affect the yield. Even when all the weather parameters remain

favourable, heavy showers during September and continuous cloudy weather may cause lower yield, as also suggested by Prabhjyot-Kaur *et al.* (2011). Grain filling and development stages are highly affected by heavy rainfall events coupled with strong winds. Clear and dry weather coupled with calm wind conditions are conducive for maturity of rice crop.

Conclusions

It may be concluded that no meteorological parameter in particular determines the growth and yield of rice at any stage. Favourable combinations of the parameters were identified and prediction models for rice yield were developed. This can be used in predicting rice yield under the prevailing weather condition in Punjab at the selected locations.

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