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Research Paper

Field and model study of rainfall pattern and its impact on wheat (*Triticum aestivum*) productivity in Uttarakhand

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ABSTRACT

The rainfall pattern aberrations during winter (*rabi*) season (December to March) in north India are a cause of concern to administrators and researchers. A field experiment was carried out during 2013–14 and 2014–15 at Roorkee, Uttarakhand, to study the effect of rainfall pattern on productivity of wheat (*Triticum aestivum* L.). It was laid down in factorial design with treatment combinations including 4 wheat varieties ('PBW 292', 'HD 2967', 'PBW 154' and 'PBW 550') and 3 sowing dates (20 November, 5 December and 20 December), replicated thrice. Soil was sandy loam, moderate in fertility. Crop was grown under best management practices. Weather data were recorded from Automated Weather Station installed at the farm. Observations were recorded on growth, development, yield and yield attributes of the crop. The results showed that the total rainfall during the growing season was similar, i.e. 222.2 mm in 2013–14 and 227.1 mm in 2014–15 but the pattern was totally different. During the winter (*rab*i) season 2013–14, a very high rainfall occurred in January (98 mm) and February (52 mm) that coincided with the grand growth phase of wheat, resulting in to bumper harvest. On the contrary, during the winter (*rabi*) season 2014–15 higher rainfall was received in March (115 mm) and April (62 mm) which coincided with flowering and grain-setting stages, resulting in reduced productivity due to lodging. The average productivity of wheat during 2013–14 was 4.37 t/ha, whereas during 2014–15 it was 3.78 t/ha. Productivity during 2014–15 was reduced by 13.6% in comparison to 2013–14. Loss in productivity was more (ranging from 11.4% to 42.1 %) in timely sown crop. The late-sown (20 December) treatment did not reveal much productivity loss and remained within 5% during 2014–15. Normal-sown varieties ('PBW 292', 'HD 2967', 'PBW 154') suffered serious productivity loss as compared to late-sown variety ('PBW 550'). DSSAT model simulated result compared well during 2013–14. However, during 2014–15 the heavy rainfall in March and April caused severe lodging and the model perhaps could not detect it.

Key words: Allowable depletion limit, Available water, Growth stages, Management allowed deficiency, Productivity, Rainfall pattern, Readily available water

Wheat is the most important staple foodgrain crop in India. It is rich in proteins, vitamins and carbohydrates and provides balanced food. It is a winter season (*rabi*) crop in Uttar Pradesh, Punjab, Haryana, Himachal Pradesh and Jammu and Kashmir. Wheat requires cool climate with moderate rainfall, flat and well-drained fertile soils for better growth and development. In the last few years, the climate in terms of rainfall pattern of Uttarakhand (India) has witnessed a phenomenal change. The rise in temperature and rainfall variability marked with their untimely occurrence (drought, heat, hail, cold, storms and flood) will be intensified and adversely affect agricultural production in Asian region (IPCC, 2014). The climatic aberration phenomena coinciding with critical crop-growth stages may adversely impact productivity. In north India, very high rainfall during the last week of February 2014 did not affect production of wheat but deteriorated the keeping quality of potato due to few days of water stagnation in the fields.

Many computer model studies carried out in India and abroad, have proved to be a very useful tool to forecast productivity of crops under changing climatic condition. The Decision Support System for Agro Technology Transfer (DSSAT) is one such tool comprising a number of models for simulating the growth of crops of economic significance (Jones *et al.,* 2003). The CERES wheat

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model forecast the loss of wheat productivity to the extent of 14–21% by 2050 in Iran (Koocheki and Nassiri, 2008). The DSSAT crop models not only simulate the effects of climate change on crop production but also evaluate various management and genetic options under climate change scenarios (Rao, 2002). DSSAT v4.5 was used for predicting yield of rice varieties cultivated using SRI practice in the north Indian condition (Dass *et al.,* 2012).

In view of the above the study entitled was undertaken with the objective to compare the rainfall-variability pattern of winter (*rabi*) seasons and its impact on wheat productivity.

MATERIALS AND METHODS

The field experiment was conducted during 2013–14 and 2014–15 at the Demonstration Farm, Department of Water Resources Development and Management, Indian Institute of Technology, Roorkee (29.87°N, 77.88°E and 262 above mean sea-level), Uttarakhand. The experiment was laid down in factorial design with 12 treatment combinations that included 3 dates of sowing, viz. 20 November (D1), 5 December (D2) and 20 December (D3) and 4 wheat varieties, viz. 'PBW 292' (V1), 'HD 2967' (V2), 'PBW 154' (V3) and 'PBW 550' (V4), and replicated thrice.

Soil was well-drained sandy loam, normal (*p*H 7.8, OC 0.45%, clays 12.5%, soil deep and free from boulders, water table below 5 m) and moderate in fertility. The crop was grown adopting best agronomic management practices (20 cm row spacing, direct seeded, irrigation as and when required, fertilizer dose 120 : 60 : 60 split in basal (40 : 60 : 60) and top-dressings (40 N and 40 N), weed controlled by intercultural operations and aphid controlled by pesticides use). Observations recorded on crop growth and development, yield (straw and grain) and yield attributes (harvest index, grains/ear, test weight and plant height at harvesting etc were statistically analyzed using XLStat. Daily weather data recorded through Automated Weather Station installed at the Demonstration Farm was analyzed and used for developing weather file.

The CERES Wheat model of DSSAT has many features to simulate and produce output files of growth and development (roots and shoots, growth and senescence of leaves and stems, biomass accumulation and partitioning between roots and shoots, leaf-area index, root, stem, leaf, and grain growth, yield and yield attributes), nitrogen mineralization and uptake, water uptake, evapotranspiration and soil water balance etc. (Timsina and Humphreys, 2006). Data generated through field experiment were utilized to validate CERES wheat crop model. Different components of genetic coefficient values taken for 4 wheat varieties in the experiment are given in Table 1.

RESULTS AND DISCUSSION

Rainfall variability

Weekly rainfall data recorded during the growing period (Meteorological week 46–16) of 2013–14 and 2014–15 are presented in Fig. 1. The total rainfall recorded during the growing period was 222.2 mm and 227.1 mm in 2013–14 and 2014–15 respectively. A comparative analysis of rainfall distribution showed that the rainfall received from sowing to boot-leaf stage was 113.2 mm and 54 mm,

Table 1. Genetic coefficients of different wheat cultivars

Cultivars	P_1V	P_1D	P_5	G_1	G_2	G_3	PHINT
'PBW 292'	26	80	650	21	41	1.5	95
'HD 2967'	20	95	600	22	45	1.5	95
'PBW 154'	24	80	650	24	38	1.5	95
'PBW 550'	31	80	700	25	45	1.5	95

P_1V, Vernalization sensitivity coefficient; P_1D, photoperiod sensitivity coefficient; P_5, thermal time from the onset of linear filling to maturity; G_1, kernel number per unit stem; G_2, standard kernel size under optimum conditions (mg); G_3, standard, non-stressed dry weight (total, including grain) of a single tiller at maturity (g); PHINT, thermal time between the appearance of leaf tips (degree-days).

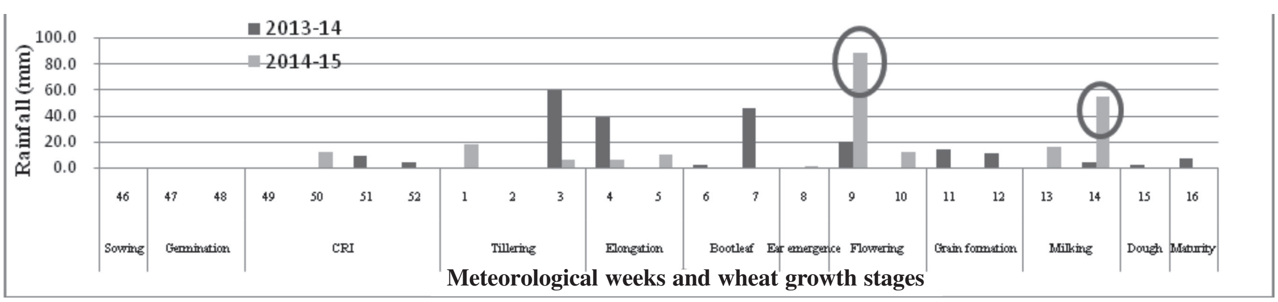

Fig. 1. Weekly rainfall pattern during wheat-growing season

whereas from flowering to maturity 109 mm and 173.1 mm during 2013–14 and 2014–15 respectively. The total rainfall was almost same but the pattern was remarkably different. The stage-wise rainfall-distribution pattern recorded during 2013–14 was, 65% at elongation, 20% at ear emergence, 9% at flowering stage and rest 6% at other stages. This was very convenient for growth, development and production of wheat. But during 2014–15 the rainfall-distribution pattern recorded was, 6% at elongation, 6% at ear emergence, 44% at flowering and 31% at grain formation and the rest 13% at other stage. This was although convenient for growth and development but was not convenient for grain production.

About 75% rainfall occurring at reproductive and maturity stage, resulted in crop lodging. Shifting rainfall pattern during the rainy (*kharif*) season (June–October) for the Haridwar district has already been reported (Tripathi *et al.,* 2008). Extreme weather scenarios particularly with rainfall and temperature has been reported (IPCC, 2014). The 75% rainfall of the wheat crop season falling only at the reproductive stage during 2014–15 in Haridwar district could be a reflection of rainfall extremes.

Soil moisture regime

The DSSAT predicted soil-moisture regime during 2013–14 and 2014–15 is presented in Fig. 2 a,b,c. The difference in soil-moisture regime between wheat varieties in either years was not noticeable but was remarkably different in each dates of sowing. The average soil-moisture regime during the crop period 2013–14 and 2014–15 was almost the same and recorded as 191 mm and 183 mm in D1 (sown on 20 November); 191 mm and 200 mm in D2 (sown on 5 December) as well as 188 mm and 176 mm in D3 (sown on December 20) respectively. This indicated that the soil-moisture regime in the wheat crop was very good, as it was close to ±10 mm of MAD or ADL (180 mm and equivalent to 50% of AW on sandy-loam soil). A 50–60% depletion limit in the available water is recommended for irrigation scheduling of wheat (Doorenbos and Pruitt, 1977).

The average soil-moisture content in the root zone of wheat-growing period sown on different dates (D_1, D_2 and D_3) were marginally lower during 2014–15 than 2013–14. This difference is not of much significance and might have happened due to lesser rainfall in the initial growing period. But the pattern of soil-moisture regime in 2 years of same sowing date varied remarkably. Wheat crop sown on 20 November (D1) recorded above saturated moisture regime from 60th to 100th day (elongation and grand growth stage) crop age during 2013–14 but did not adversely affect the grain yield, whereas the soil-moisture regime above-saturation point observed from 103rd–110th day (flowering stage) and 135th–140th day (grain filling and dough stage) during 2014–15, adversely affected the grain yield. During 2014–15, high soil-moisture regime created due to heavy rains at flowering and grain-formation stage caused the problem of pollengrain washing and wheat crop lodging. Root-system anchorage in the sandy soil weakens when moisture level goes above the field capacity. If this situation coincides with high wind velocity and grand growth/ reproductive/ grain-formation stage in case of medium to tall varieties of wheat then lodging is inevitable. During 2014–15, about 30–90% experimental area of the crop was lodged.

Table 2. Yield and yield attributes of wheat

Treatment	Observed grain yield (t/ha)		Harvest index		Grains/ear		Height at harvesting (cm)		DSSAT simulated grain yield (t/ha)	
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
V_1D_1	5.3	4.1	0.39	0.26	42.0	41.8	94.7	85.0	4.5	5.2
V_1D_2	4.7	3.1	0.37	0.27	46.7	35.4	80.0	69.7	4.2	4.7
V_1D_3	3.2	3.0	0.32	0.21	47.3	32.1	78.7	82.3	3.7	4.0
V_2D_1	5.8	5.5	0.29	0.32	44.0	41.9	87.7	87.3	4.9	5.8
V_2D_2	3.7	3.6	0.31	0.29	45.0	47.4	84.7	80.7	4.9	5.6
V_2D_3	4.1	4.3	0.43	0.26	47.0	48.3	84.0	78.7	4.6	4.8
V_3D_1	4.9	4.3	0.42	0.24	46.3	46.4	95.3	81.7	4.7	5.5
V_3D_2	3.6	2.5	0.31	0.22	46.7	30.4	80.7	72.7	4.5	4.9
V_3D_3	3.5	3.1	0.34	0.21	50.7	28.8	74.0	74.3	4.0	4.3
$V4D_1$	6.2	3.6	0.50	0.24	50.7	50.3	92.0	74.0	5.3	6.5
V_4D_2	4.1	4.1	0.35	0.33	44.3	45.8	82.0	71.3	5.3	6.5
V_4D_3	3.6	3.4	0.32	0.22	39.7	43.2	83.0	77.3	5.2	5.5
SEm±	0.29	0.23	0.02	0.01	0.92	2.15	1.90	1.62	0.14	0.22
CD (P=0.05)	0.62	0.50	0.04	0.02	2.00	4.69	4.13	3.54	0.31	0.48

V_1, ‘PBW 292’; V_2, ‘HD 2967’; V_3, ‘PBW 154’; V_4, ‘PBW 550’; D_1, 20 November; D_2, 5 December; D_3, 20 December

However, when the wheat crop was sown on 5 December (D_2) during 2013–14, the DSSAT model predicted the saturated soil-moisture regime during 47th to 97th day (elongation and grand growth stage). This scenario of soil-moisture was harmless to crop productivity. However, during 2014–15 when the crop was sown on the same date, the saturated soil-moisture regime prevailed from 87th–97th day (ear emergence) and 112th–127th day (flowering stage), thus proved detrimental to crop productivity. Heavy rainfall during flowering stage in wheat crop harmed the crop in 3 ways firstly by causing crop to lodge, secondly by washing the pollen-grains and thirdly by reducing the oxygen supply in the root zone. Adverse impact of continued high soil-moisture regime at reproductive stage in most of the upland crops is an established fact.

When the wheat crop was sown on 20 December (D3) during 2013–14, the DSSAT model predicted the saturated soil-moisture regime from 50th to 90th day (elongation and grand growth stage). This soil-moisture regime was harmless and productivity remained unaffected. However, during 2014–15 when the crop was sown on the same date and the saturated soil-moisture regime was recorded from 97th–112th day (flowering) only marginally reduced the crop productivity. In the scientific recommendation, 20 December is a late sown crop therefore this escaped the vagaries of nature and recorded the highest average pro-

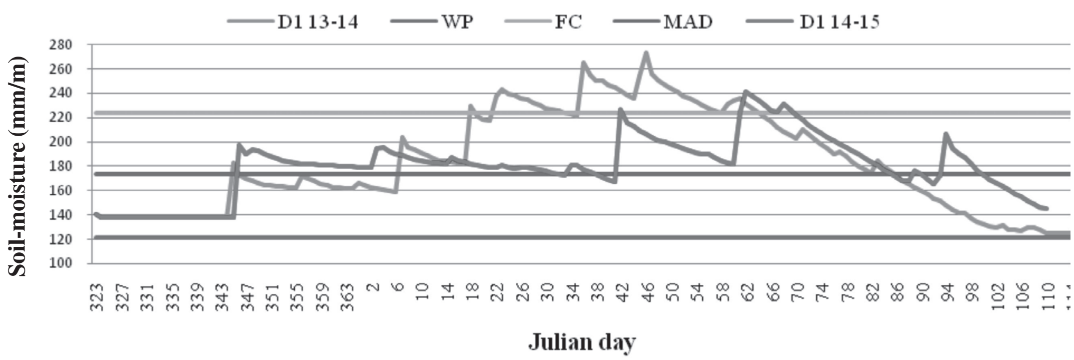

Fig. 2a. Soil-moisture regime in the root zone of wheat sown on 20 November

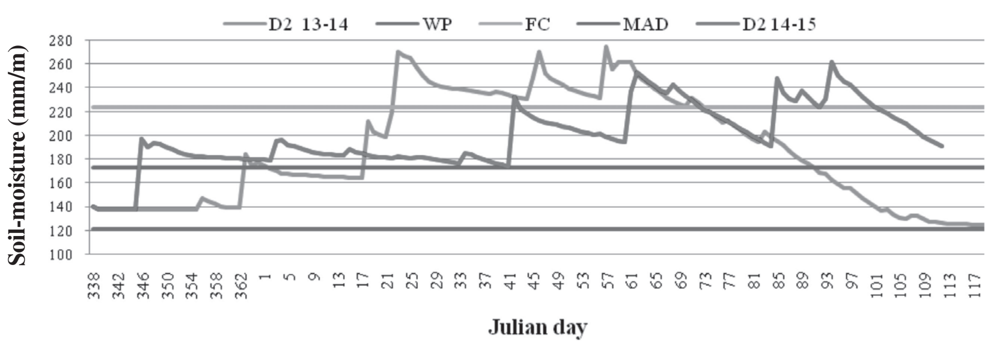

Fig. 2b. Soil-moisture regime in the root zone of wheat sown on 5 December

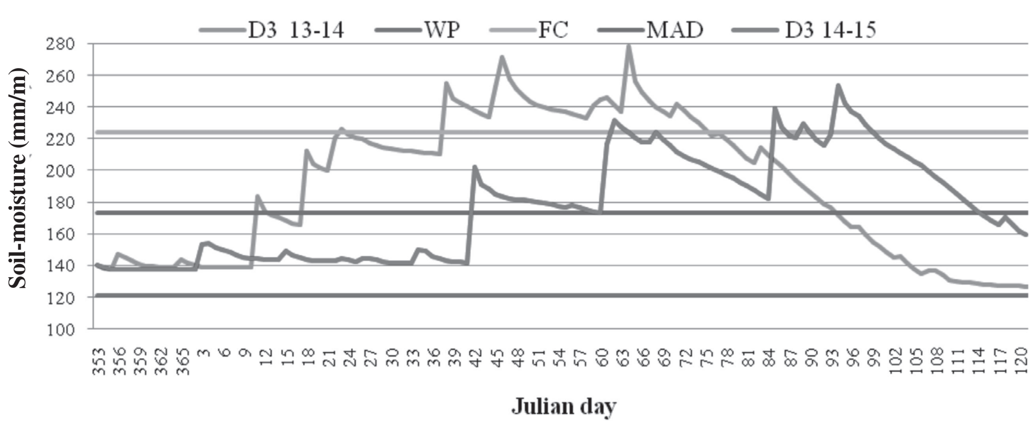

Fig. 2c. Soil-moisture regime in the root zone of wheat sown on 20 December

ductivity as compared to 25 November and 5 December sown crops. Rainfall pattern during the winter season is unpredictable. March-end rainfall occurrences during 2014–15 were not observed in the last 30 years at Roorkee (Tripathi *et al.,* 2008).

Yield and yield attributes

Yield and yield attributes are often affected by weather condition, varietal characters and agronomic management practices. A crop that is timely sown, gets better opportunity to grow and develop thus records better productivity than the late-sown crop.

Observations showed that both the years received almost the same amount of rainfall (222.2 mm in 2013–14 and 227.1 mm in 2014–15) during the wheat-growing period. But recorded substantial difference in average productivity (4.36 t/ha during 2013–14 and 3.77 t/ha during 2014–15) due to the difference in the pattern of rainfall-occurrence in the 2 years. The rainfall-distribution pattern of the crop season recorded about 75% rainfall during germination to ear emergence and 25% rainfall during flowering to maturity in 2013–14 did not cause physical damage to the crop. In 2014–15, the wheat crop season recorded the rainfall-distribution pattern of 24% during germination to ear emergence, 44% during flowering and 32% during maturity (Fig.1). Heavy rainfall at flowering and maturity caused serious problem of crop lodging.

Data presented in Table 2 showed that all the treatment combinations resulted significant difference in grain yield, harvest index (HI), grains/ear and plant height at harvesting in both the years only due to the dates of sowing. Normal sowing period recommended for wheat in the region is the last week of November. During 2013–14, in general, all the varieties recorded higher productivity when sown on 20 November (D1) and gradually reduced with advancing the date of sowing. The situation during 2014–15 got changed due to the change in rainfall-distribution pattern. About 25% rainfall was received until the ear emergence and about 75% rainfall was received thereafter. The wheat crop sown late on 20 December (D3) escaped the physical damage caused in the wake of March/ April rains 2015 due to its reduced vegetative growth and plant height.

The average harvest index recorded was 0.36 during 2013–14 and 0.26 during 2014–15 (Table 3). Reduced harvest index during 2014–15 could be ascribed to the crop-lodging problem. In general, the wheat varieties sown on 20 November during 2013–14 showed the harvest index in descending order of 0.5, 0.42 0.39 and 0.29 in ‘PBW 550’, ‘PBW 154’, ‘PBW 292’ and ‘HD 2967’ respectively. The harvest index was substantially reduced without a definite trend of varieties and sowing dates during 2014–15 due to the problem of crop lodging.

The average number of grains/ear recorded was 45.9 and 41.0 during 2013–14 and 2014–15 respectively. During 2013–14, the number of grains/ear in different varieties was 45.3, 45.3, 47.9 and 44.9 in ‘PBW 292’, ‘HD 2967’, ‘PBW 154’ and ‘PBW 550’ respectively. However, the trend recorded during 2014–15 was different (Table 2, Fig. 3c). Based on the results of grains/ear, it is concluded that the appropriate sowing date for ‘PBW 292’, ‘PBW 154’ and ‘PBW 550’ is 20 November, whereas for the ‘HD 2967’ is 20 December.

Plant height before harvesting is presented in Table 2. During 2013–14, all the varieties (‘PBW 292’, ‘HD 2967’, ‘PBW 154’ and ‘PBW 550’) exhibited reduced height by delaying the sowing date. However during 2014–15, due to crop-lodging problem pattern was not consistent.

DSSAT yield prediction

DSSAT CERES wheat model was used to simulate the grain yield of wheat crop using four wheat varieties, viz. ‘PBW 292’, ‘HD 2967’, ‘PBW 154’ and ‘PBW 550’ on 3 dates of sowing (20 November, 5 December and 20 December). Genetic coefficient values were available in our laboratory. Soil, weather and experiment files were created. Model was run and grain yield results obtained are presented in Table 3. Observation revealed that the average yield predicted (5.24 t/ha) for 2014–15 was remarkably higher than that of the yield predicted (4.65 t/ha) for 2013–14. These results were contrary to the results of actual field experiment (4.36 t/ha during 2013–14 and

Table 3. Grain yield increase or decrease (%) recorded during 2014–15 over 2013–14 in the experimental observations and DSSAT simulation.

Treatment	Grain yield increase or decrease (%) during 2014–15 over 2013–14	
	Experimental observation	DSSAT model simulation
V_1D_1	–21.3	14.8
V_1D_2	–34.9	12.0
V_1D_3	–4.7	7.7
V_2D_1	–6.0	17.7
V_2D_2	–2.1	16.1
V_2D_3	5.7	6.2
V_3D_1	–11.8	15.6
V_3D_2	–29.6	7.9
V_3D_3	–11.4	6.5
V_4D_1	–42.1	16.6
V_4D_2	1.1	21.2
V_4D_3	–3.6	6.8
Mean	–13.6	12.7

V_1, ‘PBW 292’; V_2, ‘HD 2967’; V_3, ‘PBW 154’; V_4, ‘PBW 550’; D_1, 20 November; D_2, 5 December; D_3, 20 December

3.77 t/ha during 2014–15). The DSSAT model predicted about 7% higher grain yield during 2013–14 and about 40% higher grain yield during 2014–15 over the actual. This huge deviation could be attributed to the crop-lodging problem faced by the crop during 2014–15. This indicated that the model considered only the root zone soil-moisture status in which uptake was easy and crop grew without water stress. But the physical damage part (lodging) that occurred during 2014–15 was not considered by the model. This indicated the further upgradation of DSSAT CERES wheat model incorporating the physical damages (hailstorms and heavy rain accompanied with high wind velocity etc) to improve its efficiency and applicability.

Yield loss assessment

Although the *rabi* seasons of 2013–14 and 2014–15 were equally good with respect to total rainfall occurrence, but the agronomic changed due to the difference in distribution pattern. Field experimental and DSSAT model simulation results depicting the grain yield loss or gain during 2014–15 over 2013–14 are presented in Table 3. In general, the experimental observation recorded the yield loss of –13.6%, whereas the DSSAT model simulated the yield higher by 12.7% in 2014–15 over 2013–14.The contrary observations confirm the inherent weakness of model under abnormal weather condition and needed improvement to accommodate the same. The DSSAT model under normal weather condition has been successfully used to assess the yield loss in SRI grown rice (Dass *et al.,* 2012).

Yield loss recorded in the experimental observation in different treatment combinations in the descending order of V4D1 (–42.1%), V1D2 (–34.9%), V3D2 (–29.6%), V1D1 (–21.3%), V3D1 (–11.8%), V3D3 (–11.3%), V2D2 (–6%), V1D3 (–4.7%), V4D3 (–3.6%) and V2D2 (–2.1%). Exceptionally increased yield of no statistical significance was also recorded in 2 treatments, i.e. V2D3 (5.7%) and V4D2 (1.1%). In general, the yield loss decreased with advancing the date of sowing. Crop sown on 20 November, 5 December and 20 December showed the yield loss of –20.3%, –16.4% and –3.5% respectively. Wheat varieties also responded differently to yield loss. Yield loss was –20.3% in 'PBW 292', –0.8% in 'HD 2967', –17.6% in 'PBW 154' and –14.9% in 'PBW 550'. Under the normal weather condition, the optimal wheat-sowing period has been observed from 01–15 November (Meena *et al.,* 2015).

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