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EDITORIAL

Since its inception in 1999, the Association of Agrometeorologists has been able to reach across the globe crossing the number of life members to 1100, which is mainly attributed to its official publication the Journal of Agrometeorology. The journal is being published regularly since 1999 appearing in June and December. Besides, the special issues are also published based on paper presented in seminars organised by the Association. There was a sea-change in 2008 with the Association organizing its first international conference at CRIDA Hyderabad. The proceedings of the conference were brought out in special issues of the journal with a new get up and quality contents. These publications boosted the journal to international arena facilitating to achieve international impact factor in 2009 and thereby a quantum jump in NAAS rating. All credit goes to the authors whose papers have been referred internationally. This has not only attracted the scientists across the discipline in India but also from the foreign countries towards the Journal of Agrometeorology. This has further encouraged scientists to relate and substantiate their work with agrometeorological data and information. With NAAS rating of more than 6 in recent years, the number of manuscripts received for publication has increased tremendously. In spite of our best efforts to accommodate all good quality approved papers, though the page limit of each issue was increased from 100 to 175, still, being half yearly publication, there was a lock-in period of six months for the papers to be published after the acceptance. Hence, on the demand of members and some editorial members, it is decided that the frequency of the publication be increased to quarterly appearing in March, June, September and December without compromising with the quality of papers. In order to make the publication cost effective, the number of hard copies will be reduced. Most of the members would be provided with a soft copy of the journal. This is the first quarterly issue of year 2017. I am sure this new initiative would fulfill the dreams of many members/authors and will further add another feather to the laurels of the Journal of Agrometeorology.

Vyas Pandey

Managing Editor

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Effect of reduced PAR on growth and photosynthetic efficiency of soybean genotypes

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ABSTRACT

Soybean is an important crop, and physiologically, it is photosensitive in nature and therefore, is likely to be highly affected by the atmospheric brown clouds (ABCs) which reduce PAR (Photosynthetically Active Radiation) availability, and moisture stress conditions those may prevail as a consequence of climate change scenario. Therefore, the impact of reduced natural PAR was evaluated on its determinate (DT; cv. JS-93-05), semi-determinate (SDT; cv. JS-335) and indeterminate (IDT; cv. Kalitur) genotypes. For simulating the reduced PAR condition, three different shapes of structures, *viz*., rectangular-cuboid, octagonal-dome and hemispherical-dome with shade-net covering were initially tested to check the uniformity of PAR availability inside the structure and the last one was found better. The light saturation point (LSP) was found to be 800, 1200 and 1000 PAR µmol $m^{-2}s^{-1}$ in case of DT, SDT and IDT genotypes, respectively. Under reduced PAR and restricted irrigation condition, the photosynthetic rate was 20.8, 21.9 and 28.9 µmol $m^{-2}s^{-1}$ in case of DT, SDT and IDT cultivars, respectively, while their seed yields were 151.3, 238.7 and 264.2 kg ha^{-1} indicating better source-sink relations of the IDT cultivar. Therefore, it is projected that IDT cultivars are likely to be popular under futuristic scenarios of low PAR availability and water scarcities.

Keywords: Light saturation point, PAR, Photosynthesis, Shade-net structure, Source-sink relationship, Soybean.

Atmospheric particles generally termed aerosols, significantly perturb the atmospheric absorption of solar radiation by scattering/absorbing solar radiation and emitting/absorbing long wave (IR) radiation. However, aerosol concentration changes with altitude, regulate the radiation fluxes at the surface as well as at the top of the atmosphere and affects ambient temperature also. In addition, they reflect some of the incoming solar radiation back to space, cooling the earth's surface, and at the same time absorbs some of the energy coming from sun, heating the atmosphere around them. But the magnitude of aerosol energy absorption on the global scale and its contribution to global warming are uncertain (Seinfeld, 2008). ABCs (Atmospheric Brown Clouds) induced atmospheric heating and surface dimming are large over Asia in general and over India and China, in particular (Ramanathan *et al*., 2007). For India, the observed surface dimming trend was 4.2 Wm^{-2} per decade (about 2 per cent per decade) during 1960 -2000, while it accelerated to 8 Wm^{-2} per during the period between 1980–2004. Cumulatively, these decadal trends suggest a reduction of about 20 Wm^{-2} from 1970s-2002 and are projected to increase as per future projections (Ramanathan *et al*., 2007).

Another potential environmental effect of ABCs is their large effect in reducing the total (direct + diffuse) PAR. The brown clouds over the Arabian Sea decreased direct PAR by 40 - 70 per cent, but enhanced the diffuse PAR substantially, with a net reduction in total PAR by 10 - 30 percent (Meywerk and Ramanathan, 2002). The potential impact of large reductions in direct PAR and corresponding enhancements in diffuse PAR accompanied by net reduction in total PAR on marine and terrestrial photosynthesis and on agricultural productivity (Bal *et al.,* 2004; Chameides *et al*., 2002; Stanhill and Cohen, 2001) have not been adequately reported. Very few studies have examined the impacts of ABCs on agriculture (Chameides *et al*., 1999; UNEP, 2002), but it needs to be mainly focused on the impact of solar radiation on yield and productivity. The estimations are that the dimming effect of ABCs has reduced rice yield by 6–17 per cent (Auffhammer *et al*., 2006). For wheat and rice, yield reductions up to 8 per cent were predicted in India when single effect of aerosols on radiation was considered by crop simulation models (UNEP, 2008). However, when cooling effect was also incorporated in the model, it nullified the yield reductions due to enhanced crop duration effect (UNEP, 2008). The reduction in PAR may or may not reduce the yield of photo-insensitive crops, but certainly, it will hamper the yield potential of photo-sensitive crops like soybean (Ramanathan *et al*., 2007).

As soybean is a photo-sensitive crop and the yield gets negatively affected by surface dimming Brazil has started adopting indeterminate soybean varieties (Anonymous, 2012). In Brazil, the 50 per cent of cultivated area of determinate soybean genotypes were replaced and occupied by indeterminate genotypes and it is expected to eventually reach 100 per cent (Anonymous, 2012). The huge advantage of indeterminate varieties over determinate varieties was that they could recuperate after periods of dry weather. Under hot and dry weather the indeterminate varieties which are at flowering stage, may abort their flowers and pods to escape the conditions, they recovers with new flush of flowers once rainfall occurs. In India, about 70 per cent soybean area is cultivated with semi-determinate genotypes, around 20 per cent with determinate and only 10 per cent with indeterminate genotypes. Therefore, experiments were conducted to i) develop suitable shade-net structures for simulating reduced PAR condition, ii) determine the light saturation point (LSP) for maximizing photosynthesis among the soybean genotypes iii) identify the better performing cultivars under reduced PAR and moisture stress conditions.

MATERIALS AND METHODS

The experiments were conducted at ICAR-National Institute of Abiotic Stress Management (NIASM), Baramati (latitude: 18°09'N, longitude: 74°30'E, elevation: 550 MSL), Pune, Maharashtra, India during two *Kharif* seasons in 2013 and 2014.

Crop raising conditions

The experiment was carried out in black 60-70 cm deep silty clay soil (around 40 % clay) developed over native basaltic terrain. Baramati is prone to drought and characterized by low and erratic rainfall. The long term annual rainfall is 588 mm of which about 71 per cent is received during the four months of southwest were monsoon season (June-September). Prevailing weather conditions during the two experimental *kharif* seasons of 2013 and 2014 monitored at automatic weather station (AWS).

Seed materials and experimental design

Soybean genotypes of determinate (JS-93-05), semi-determinate (JS-335) and indeterminate (Kalitur) used for the conduct of experiment was obtained from Agharkar Research Institute (ARI), Regional Station, Wadgaon-Nimbadkar, Pune, India. The field was initially prepared to pulverize the soil and thereafter, ridges and furrows were created using a mini tractor. Sowing was done on 21st July in 2013 and 14th July in 2014. The experiment was conducted under split plot design with three replications having two irrigation levels i.e. normal irrigation (NI) and restricted irrigation (RI) (withheld irrigation at 60 DAS, i.e., *anthesis period*); and three genotypes of contrasting growth characteristics, namely, Determinate (JS-93-05), Semi-determinate (JS-335) and Indeterminate (Kalitur), in sub-plots having size of 8.0 x 4.5m^2. Total water applied in normal and restricted irrigations were 18 and 12 cm during 2013; 24 and 18 cm during 2014, respectively. Three irrigations in 2013 and four in 2014 were applied under normal irrigation while in restricted irrigation it was two and three, respectively. The irrigation frequencies between two years were differed due to variation in time and amount of rainfall. Recommended practices were followed for fertilizer application, and weed and insect-pests control.

Selection of shade-net and design of shade-net structure

Three shade-net structures of different shapes which are generally used for experimental purpose namely; rectangular-cuboid (6 m length x 4 m width x 3 m height), octagonal-dome (6 m diagonal length, 3 m height) and hemispherical-dome (6 m diameter, 3 m height) were fabricated to evaluate and standardize the uniformity of PAR availability within the structures (Fig. 1). The corrosion resistant iron pipe (25-50 mm diameter and 14-16 gauge thickness) was used for fabrication; which could withstand and protect the structure during entire growth stages from the extreme wind and rain. About 0.25 m distance was maintained between bottom side and ground surface for all shade-net structures using iron stand to avoid temperature rise and uniform air flow within the structure. The shade-net structures were covered with the research grade white shade-net (25% reducing factor of sunlight). During construction and selection of shade-net, intensive care was taken to test the PAR availability without affecting the other parameters *viz*., temperature and relative humidity. The PAR observations were recorded randomly from 20 different fixed points in each shade-net structure at three different heights of 0.5m, 1.0m and 1.5m from the ground level.

Photosynthetically active radiation

The PAR availability was measured using Line quantum sensor (LI-191S, LICOR). Twenty sample points were marked inside shade-net structures of the three shapes, at three heights, viz. 0.5m, 1.0m and 1.5m on a grid pattern and observations were recorded at one hour interval from 09:30 am to 04:30 pm with shade-net of 25% reduced factor. PAR reduction was calculated by using the following formula:

Reduction in PAR (%)

$$= 100 - \frac{\text{PAR availability inside the structure}}{\text{PAR availability outside the structure}} \, x \, 100$$

Photosynthetic assimilation rate (A)

The photosynthetic assimilation rate of soybean genotypes was measured by Advance Photosynthetic System *GFS-3000* (WALZ, Germany). Gas exchange measurements were made between 10.30 am and 11.30 am IST on generally cloud free days. For measuring photosynthetic assimilation rate (A), stomatal conductance (g_s) and transpiration rate (E) in light, photosynthetic leaf chamber (*model*: GFS-3010-S) was clipped onto the attached leaf, which had been exposed to sunlight. The chamber was held in such an angle that the enclosed leaf surface faced the sun, to avoid shading inside the curette. The irradiance at the upper surface of the leaf chamber was measured by calibrated sensor (filtered silicon photocell, *model*: 3055-FL) mounted on the same surface of the leaf chamber. It was 1300 ± 50 PAR µmol m^{-2} s^{-1} outside during the most photosynthesis measurements; and the temperature, relative humidity and CO_2 concentration were 26.1 ± 2°C, 68 ± 2% and 390 ± 15 µmol CO_2 mol^{-1}, respectively. The photosynthesis and stomatal conductance become stable within 2 minutes after clipping the selected attached leaf experiencing saturated solar irradiance and values on photosynthesis gas exchange were then recorded. Measurements were made on six different plants on the third leaf from the stem apex. The photosynthetic assimilation rate (A) was calculated as given by Caemmerer and Farquhar (1981)

$$A = \frac{u_e \, x \, (c_e - c_o)}{LA} - (E \, x \, c_o)$$

Where,

A = Photosynthetic assimilation rate [µmol m^{-2} s^{-1}],

u_e = Molar flow rate at the inlet of the cuvette [µmol s^{-1}],

c_o = CO_2 mole fraction at the outlet of the cuvette [ppm],

c_e = CO_2 mole fraction at the inlet of the cuvette [ppm].

LA = Leaf area [cm^2],

E = Transpiration rate [mmol m^{-2} s^{-1}]

Growth and yield parameters

The plants were harvested after physiological maturity, and separated into leaf, stem, pods and fractions. Plant height of each plant was measured in each subplot of irrigation treatments and control (well-irrigated) plots. Dry weights of plant parts and seeds were measured after drying at 80°C in a hot air oven for 72 hours.

Statistical analysis

The data obtained from the above experiment were analysed in split plot design as given by Panse and Sukhatme (1967). The significance of difference was evaluated by 'F' test at 5% level of significance. Accordingly, the critical differences were calculated.

RESULTS AND DISCUSSION

Development of equal PAR distribution shade-nets

Surface dimming is an atmospheric stress from photosynthetic efficiency view point and it will increase in future (Ramanathan *et al*. 2007). Hence, it was necessitated to establish a methodology to simulate surface dimming in closed environments for experiment purpose. Before the conduct of the experiment and to understand its impact on photosensitive crops like soybean, it was imperative to test the uniformity of PAR availability within the shade-net structures. Therefore, different shapes of structures were tested to select the ideal one. Among the structures, the hemispherical-dome shape structure was most stable in field conditions as compared to octagonal-dome shape and rectangular-cuboid shape structures (Fig. 1). Furthermore, by recording the PAR values at 0.5m, 1.0m and 1.5m height above the ground level, it was observed that the hemispherical-dome shape structure provided more uniform availability of PAR inside the structure followed by octagonal-dome shape and rectangular-cuboid shape structures (Fig. 2). Distribution of PAR was also found uneven in both rectangular-cuboid and octagonal-dome structures during morning and late afternoon hours. Dey and Deka (2012) reported that the shape of the dome encloses maximum amount of space with least surface area for which dome's surface area requires lesser quantity of expensive building materials, which reduces cost and improves efficiency too.

Perusal of height of observation clearly reveals that, amongst three structures tested (Table 1), hemispherical-dome shape had resulted uniform PAR distribution as it had not shown any significant difference from centre to corners

Table 1: Mean value of PAR reduction in rectangular-cuboid shape (R), octagonal-dome shape (O) and hemispherical-dome shape (H) structures.

Height of observation	0.5 m R	0.5 m O	0.5 m H	1.0 m R	1.0 m O	1.0 m H	1.5 m R	1.5 m O	1.5 m H
Factor A									
A1	28.1	24.7	25.2	28.1	24.7	25.3	29.2	25.7	25.3
A2	25.7	24.3	25.3	25.7	24.4	25.6	26.8	25.4	25.6
A3	25.6	24.0	25.3	26.7	24.1	25.1	25.9	25.2	25.3
A4	26.7	24.5	25.3	28.0	24.5	25.8	27.4	25.6	25.2
C.D. (P=0.05)	0.6	NS	NS	0.9	NS	NS	0.5	NS	NS
Factor B									
B1	24.2	24.5	25.2	24.7	24.6	25.2	26.1	25.4	25.6
B2	26.8	24.6	25.4	27.2	24.7	25.4	27.1	25.5	25.2
B3	26.4	25.6	25.3	26.9	25.6	25.3	26.7	26.7	25.1
B4	25.2	24.6	25.2	25.9	24.6	25.3	27.0	26.1	25.1
B5	27.8	24.2	24.8	28.4	24.2	24.6	29.0	25.0	25.5
B6	28.8	23.9	25.7	29.4	23.9	25.7	28.1	24.7	25.5
B7	25.4	24.2	25.9	26.0	24.2	25.9	27.5	25.1	25.8
B8	27.8	23.6	26.0	28.4	23.6	26.0	27.2	25.2	25.5
C.D. (P=0.05)	0.8	0.6	NS	1.00	0.9	NS	0.8	0.7	NS
Interaction	S	S	NS	S	S	NS	S	S	NS

Where, A1 = Right outer border within the structure; A2 = Right inner border within the structure; A3 = Left outer border within the structure; A4 = Left inner border within the structure; B1, B2, B3, B4, B5, B6, B7 and B8 are time of observations at 09:00 am, 10:00 am, 11:00 am, 12:00 pm, 01:00 pm, 02:00 pm, 03:00 pm and 04:00 pm, respectively.

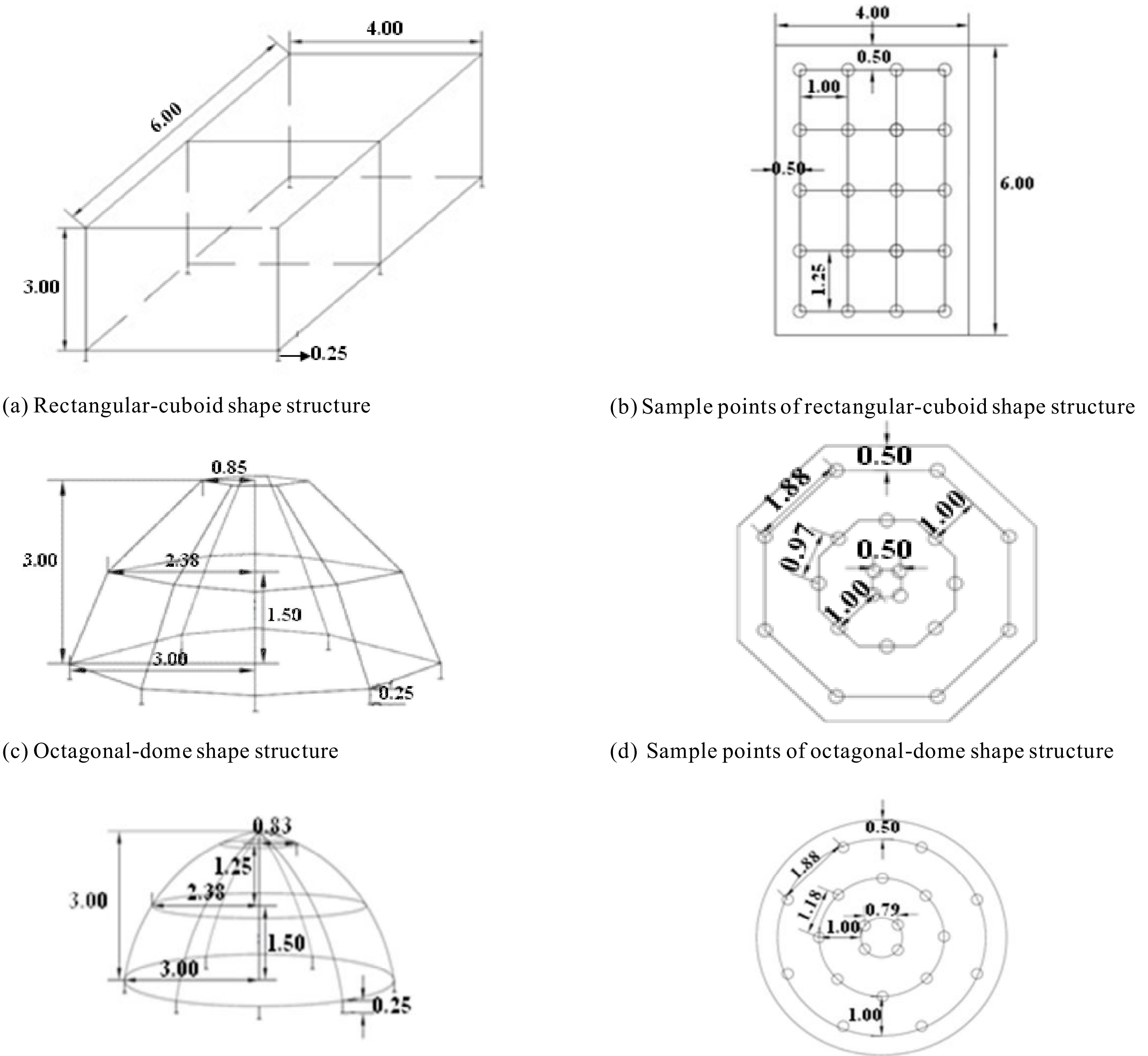
as well as time of observation. Octagonal-dome and rectangular-cuboid structures exerted significant variation in terms of time of observation and from centre to corners. Therefore, due to homogeneity in terms of PAR availability within the structure in hemisphere-dome shape structure as compared to rectangular-cuboid and octagonal-dome shape structures, the hemisphere-dome shape structure was identified as the most appropriate for conducting such type of research work.

Determination of light saturation points for maximum photosynthesis among soybean genotypes

Photosensitivity plays an essential role in the response of plants to their changing environments throughout their life cycle. Being a photosensitive crop, soybean needs specific PAR range for photosynthesis beyond which its production is affected drastically. Light saturation point was measured by giving different levels of PAR from 200 to 1600 μmol m^{-2} s^{-1} at canopy level of all the three genotypes. The determinate genotype (JS-93-05) showed its light saturation point near to 800 PAR μmol m^{-2} s^{-1} with photosynthetic rate of 20.77 μmol m^{-2} s^{-1} (Fig. 3), whereas semi-determinate soybean genotype JS-335 shown its light saturation point near to 1200 PAR μmol m^{-2} s^{-1} with photosynthetic rate of 21.95 μmol m^{-2} s^{-1}, while indeterminate soybean genotype Kalitur shown its light saturation point near to 1000 PAR μmol m^{-2} s^{-1} with photosynthetic rate of 28.88 μmol m^{-2} s^{-1}. Therefore it can be interpreted that indeterminate soybean genotype Kalitur will perform better in terms of photosynthetic rate which is directly proportional to the yield as compared to the determinate and semi-determinate types under future PAR scenario due to more aerosol and increase in cloudy days.

Yield variation among soybean genotypes under reduced PAR and restricted irrigation

To understand the response of different soybean genotypes under restricted irrigation condition during



(a) Rectangular-cuboid shape structure

(b) Sample points of rectangular-cuboid shape structure

(c) Octagonal-dome shape structure

(d) Sample points of octagonal-dome shape structure

(e) Hemispherical-dome shape structure

(f) Sample points of hemispherical-dome shape structure

Fig. 1: Schematic diagrams of rectangular-cuboid shape structure (a) and layout of sample point used (b); octagonal-dome shape structure (c) and layout of sample point used (d); hemispherical-dome shape structure (e) and layout of sample point used (f) to test the uniformity of PAR availability within the structure (all dimensions in meter).

reproductive stage, irrigation was withheld at 60 DAS (i.e. anthesis period). Due to this restricted irrigation, per cent reduction in terms of number of pods per plant (Table 2) was recorded minimum in indeterminate Kalitur (7.48%), followed by JS-93-05 determinate (25.26%) and semi-determinate JS-335 (33.33 %). Under restricted irrigation condition, indeterminate genotype Kalitur (66.8) performed better in number of pods per plant as compared to semi-determinate JS-335 (37.6) and determinate JS-93-05 (35.5). Similarly per cent reduction in terms of grain yield (q ha^{-1}) was recorded minimum in indeterminate Kalitur (7.43%), followed by semi-determinate JS-335 (17.80%) and determinate JS-93-05 (37.09 %). Under restricted irrigation condition, indeterminate genotype Kalitur (264.2 kg ha^{-1}) performed better in terms of grain yield (q ha^{-1}) as compared to semi-determinate JS-335 (238.7 kg ha^{-1}) and determinate JS-93-

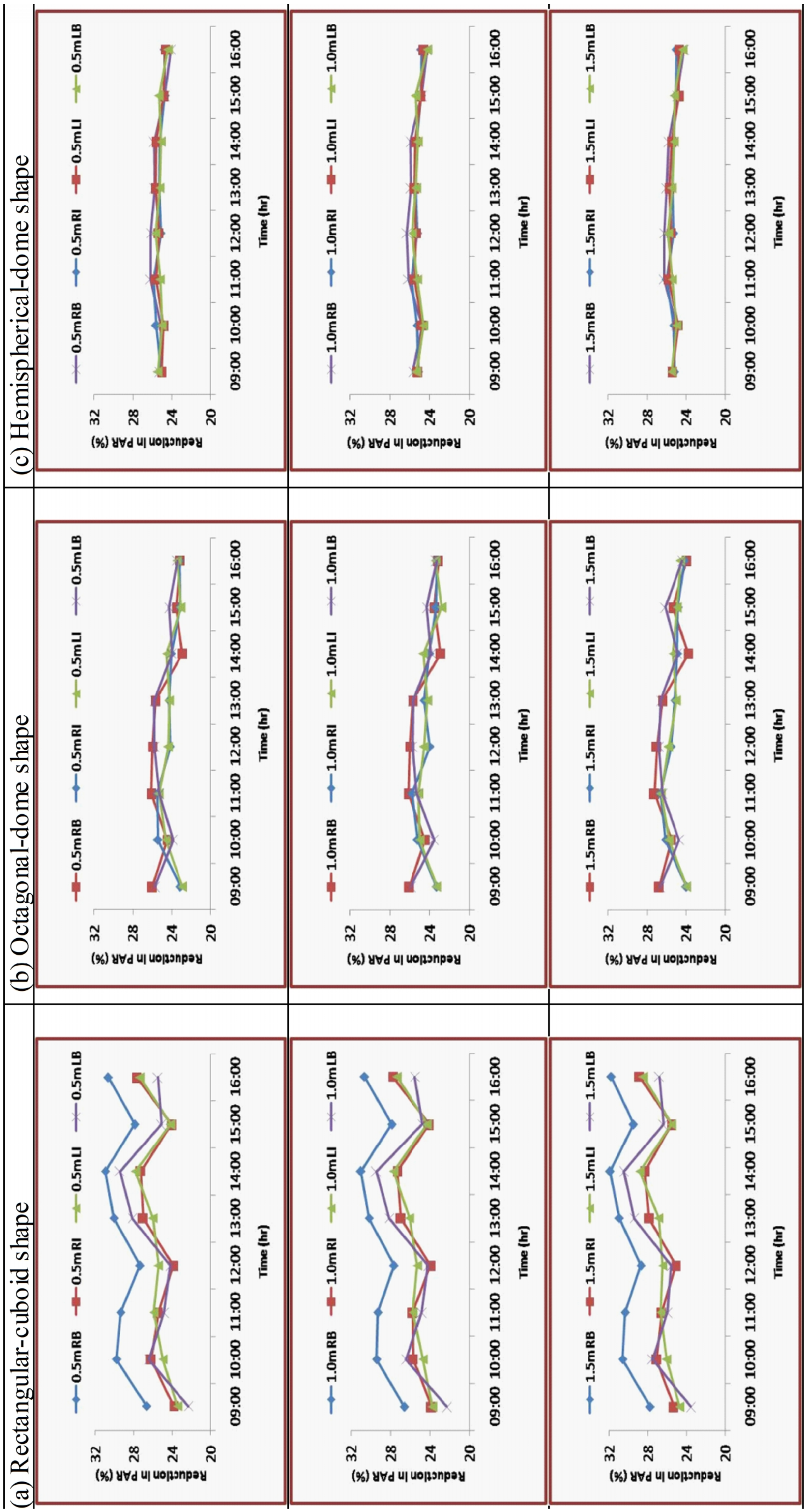


Fig. 2: Reduction in PAR availability (in %) under rectangular-cuboid (a), octagonal-dome (b) and hemispherical-dome (c) shape structures at the height of 0.5 m, 1.0 m and 1.5 m from ground surface of right border (RB), right internal (RI), left internal (LI) and left border (LB).

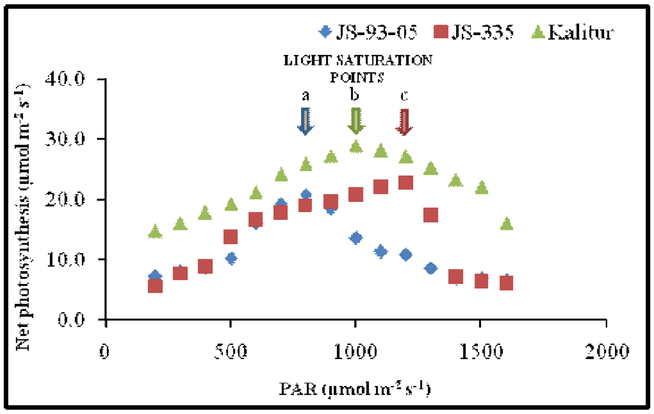


Fig. 3: Light saturation point of determinate (arrow 'a'), semi-determinate (arrow 'b') and indeterminate (arrow 'c') soybean genotypes.

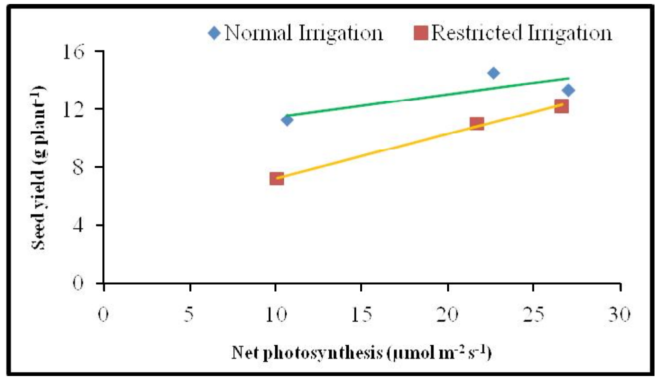


Fig. 4: Representation of variation in source (net photosynthesis) and sink (seed yield) relationship among the genotypes under normal irrigation and restricted irrigation conditions.

05 (151.3 kg ha^{-1}). The only problem with the indeterminate soybean genotype (Kalitur) was more shattering of the pods, if kept for longer time in the field after harvest maturity. Therefore, it is suggested that it should be harvested immediately after physiological maturity. From the above results, we brought to a close that the semi-determinate and indeterminate genotypes performed better under normal irrigated conditions (Table 2) in terms of grain yield as compared to determinate types, whereas, under restricted irrigation condition (60 DAS), indeterminate soybean genotype (Kalitur) performed better as compared to semi-determinate (JS-335) and determinate (JS-93-05) genotypes. Therefore, indeterminate soybean genotype (Kalitur) may be a better option to replace semi-determinate and determinate soybean genotypes for higher/sustainable production under reduced PAR scenario as Auffhammer *et al*. (2006) estimated that the reduction in PAR availability reduces rice yield.

Source and sink relation among soybean genotypes under reduced PAR and restricted irrigation

The varied relationship between source and sink was assessed among different genotypes (Fig. 4). The relationship was positive in both normal and restricted irrigation conditions and it was significant under restricted irrigation condition. Under restricted irrigation conditions, the source in terms of net photosynthesis was minimum in determinate (JS-93-05) genotype even under maximum PAR availability required. It clearly indicates that restricted irrigation hampered the partitioning of photosynthates in JS-93-05. The reduction in source and sink relation was almost two folds in case of JS-93-05 while the ratio was less in JS-335 and Kalitur between two irrigation treatments. It was also observed that difference in source and sinks relationship was not significant in Kalitur under both normal and restricted irrigations. These results indicate that the source and sink relationship at reproductive phase of determinate genotype JS-93-05 was affected due to restriction of irrigation and reduced PAR availability, whereas the JS-335 and Kalitur adapted better to restricted irrigation by skipping its reproductive phase.

Genotypic variations under reduced PAR and restricted irrigation conditions

As a convention, the surface dimming will affect more to photo-sensitive crops. In this study indeterminate soybean genotype performed better under reduced PAR compared to the determinate and semi-determinate soybean genotypes. At the same time, it also performed better under restricted irrigation condition, and hence, it may be taken as future option to replace semi-determinate and determinate soybean genotypes with indeterminate one for higher/sustainable production particularly under reduced PAR as well as limited availability of irrigation water. Restricted irrigation had marked deleterious effect on number of pods/plant, seed yield and biomass production as compared to normal irrigation. Indeterminate Genotype (Kalitur) had recorded significantly higher number of pods per plant and biomass production as compared to determinate and semi-determinate genotypes, while in terms of seed yield it was at par with semi-determinate genotype. Interaction effect was found significant for number of pods per plant, seed yield and biomass production. Indeterminate genotype Kalitur under normal irrigation generated significantly highest no. of pods/plant and biomass production and was followed by semi-determinate genotype (JS-335) grown under restricted

Table 2: Yield and yield attributes in determinate, semi-determinate and indeterminate soybean genotypes

Yield Parameters	Determinate (JS-93-05)			Semi-determinate (JS-335)			Indeterminate (Kalitur)		
	NI	RI	Reduction (%)	NI	RI	Reduction (%)	NI	RI	Reduction (%)
No. of pods plant^{-1}	47.5	35.5	25.3	56.4	37.6	33.3	72.2	66.8	7.5
Biomass (g plant^{-1})	41.3	32.4	21.6	48.8	39.4	19.1	55.1	51.0	7.4
Seed yield (g plant^{-1})	11.3	7.2	36.0	14.5	11.1	23.9	13.4	12.2	8.6
Seed yield (q ha^{-1})	24.1	15.1	37.1	29.0	23.9	17.8	28.5	26.4	7.4

Yield Parameters	No. of pods plant^{-1}			Seed yield (kg ha^{-1})			Biomass (g plant^{-1})		
	NI	RI	Mean	NI	RI	Mean	NI	RI	Mean
Determinate (JS-93-05)	47.5	35.5	41.5	240.5	151.3	195.9	41.3	32.4	36.8
Semi-determinate (JS-335)	56.4	37.6	47.0	290.4	238.7	264.6	48.8	39.4	44.1
Indeterminate (Kalitur)	72.2	66.8	69.5	285.4	264.2	274.8	55.1	51.0	53.1
Mean	58.7	46.6	52.7	272.1	218.1	245.1	48.4	40.9	44.7
CD (P=0.05)									
Irrigation (I)	8.7	3.2	5.7						
Genotype (G)	3.6	2.2	2.8						
I x G	5.0	3.2	4.0						

Where, NI = Normal irrigation; RI = Restricted irrigation

irrigation condition. Significant interaction effect was also observed in terms of seed yield and was recorded maximum in semi-determinate (JS-335) genotype grown under normal irrigation condition which was significantly superior to determinate genotype (JS-93-05) while remain statistically at par with indeterminate genotype (Kalitur) grown under normal and restricted irrigation conditions. The present study was undertaken to understand the effect of surface dimming and PAR reduction on few soybean genotypes and its mitigation options under projected climate change scenario whereas more genotypes need to be tested to abridge the research gap on this aspect.

CONCLUSIONS

Hemispherical-dome shaped shade-net structure was evaluated as an ideal option for conducting field experiments on assessing the impact of surface dimming (due to ABCs) which causes reduction in PAR availability to crops. The indeterminate soybean cultivar showed lesser impact on photosynthesis under dimmed PAR scenario and was also better suited under moisture stress conditions as compared to determinate and semi-determinate soybean cultivars. Therefore, a shift towards cultivation of indeterminate soybean genotypes is reasonably accepted in view of future projected climatic scenario as compared to popular determinate and semi-determinate cultivars in future. This study will pave the way in preparing ourselves for taking soybean crop in future. However, more research efforts are required to test large number of genotypes among different types, i.e., determinate, semi-determinate and indeterminate to validate this conclusion and assess it as a mitigation option.

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Climate change impacts vis-a-vis productivity of soybean in vertisol of Madhya Pradesh

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ABSTRACT

The impact of climate change on agricultural crops is a major concern and threats to the global food security. It also limits the potential of crops and cropping system in a given area. Therefore, the present study was aimed to assess the combined effect of positive (CO_2 fertilization, lesser temperature and higher rainfall) and negative (higher temperature, lower rainfall) impacts of the futuristic climatic scenarios on productivity of soybean using APSIM (Agricultural Production Systems sIMulator) model. We have followed the Climate-Crop Modeling Project (C3MP) methodology and generated ninety-nine sensitive test to achieve each test's temperature, rainfall and CO_2 concentration range. Using 30 years of climate data (1980-2010) of Central India as base, the simulation results showed that increasing CO_2 concentrations alone resulted in increased soybean yield. Similarly, reduction in rainfall amount indicated negative impact on it. This effect further compounded with increase in temperature and thus, reduced soybean yield. Increasing the temperature with 10% decrease in rainfall declined the soybean yield by 10%. Whereas, increase in temperature along with increase in rainfall also not resulted favorably soybean growth. Decreasing the temperature from the base by 1°C and increasing the rainfall by more than 10% benefitted the soybean productivity, whereas increasing the temperature by 1°C with no change in rainfall resulted decline in soybean productivity by 10-15%.

***Keywords*:** Climate change, CO_2, temperature, rainfall, APSIM, soybean,

In the past few decades' climate change emerged as a serious concern over the globe as it significantly affects agricultural production. It is estimated that climate change is likely to reduce world food levels by roughly 1.5 per cent per decade without any adaptation and mitigation strategies with a plausible range between 0- 4 per cent (Lobell and Gourdji, 2012). In India, more than 700 million populations directly or indirectly depend on agriculture and allied activities for their livelihood, making this sector is most sensitive to climate change. Crop growth is a function of total photosynthate produced by the source and proportion of theassimilate allocated to reproductive sinks (Lemoine *et al.,* 2013). Climatic factors such as temperature, solar radiation, relative humidity and carbon dioxide (CO_2) concentration have been shown to affect the processes of both photosynthesis and dry matter allocation in plants (Mohanty *et al.,* 2015).

Several studies showed that the earth's climate has changed since the middle of the nineteenth century (Kumar, 2016). Increasing atmospheric temperatures and CO_2 concentration along with uncertainties in annual rainfall have caused widespread reduction of yield in previous decade in many parts of globe (Coumou and Rahmstorf 2012; Kumar 2016). In India, Kumar *et al* (2010) found that maize crop is differentially affected in different region of India under future climatic scenarios.

Agricultural production in Madhya Pradesh, India is particularly vulnerable to the impacts of climate change and variability due to its largely rainfed (72% of cultivated area), subsistence nature and the substantial disparities between small-holder farm capacity in applying inputs. It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on productivity of different crops of the state. Soybean is one of the major rainy season crop in the rainfed agro-ecosystem of central and peninsular India. The state Madhya Pradesh contributes 60% of the total area under soybean production in the country. The crop is predominantly grown on vertisols and associated soils with an average crop season rainfall of about 900 mm, though this varies greatly across locations and years. Over the globe, several studies quantitatively examined the warming impacts on soybean grain yields and reported significantly decreased in grain yields with rising temperature during growing season (Rio *et al.*, 2015). But, there have been few studies in India aimed at understanding the nature and magnitude of gains/losses in yields of soybean crop under different climatic scenarios. With this backdrop, the present study was undertaken to examine the combined effects of changes in temperature, CO_2 concentration and rainfall on grain yield and biomass production of soybean in central Indian condition.

MATERIALS AND METHODS

This study was carried out on a vertisol soil of central India located at 23.28^{0}N, 77.48^{0}E. The soil of the experimental site was deep heavy clay (isohyper thermic Typic Haplustert). The top soil (0-15 cm) was low in available N (120 mg kg^{-1}), alkaline permanganate method, medium in available P (5.6 mg kg^{-1}) and high in available K (230 mg kg^{-1}). The pH (1:2), CEC, bulk density of the surface soil 0–15 cm) were 7.8, 46 cmol (+) kg^{-1} soil and 1.30 Mg m^{-3}, respectively, while water holding capacity at saturation, field capacity (-33 kPa) and permanent wilting point (-1,500 kPa) were 62.8, 38.9 and 24.6 % (v/v), respectively. The climate of the experimental site was hot sub-humid type with a mean 132 annual rainfall of 1,130 mm and potential evapotranspiration of 1,400 mm. About 80 per cent of the rainfall occurs during 134 the rainy season, i.e. June to September. Average maximum monthly temperature (40 ^{0}C) was reached in May, while the minimum (9^{0}C) was in January.

A crop growth simulation model 'APSIM' in conjunction with actual and modified long-term historical climate data was used to assess the potential impact of climate change on soybean yield in Bhopal. APSIM consist of well-tested algorithms that deals nitrogen, water, crop residues with climate effects on crop growth (Keating *et al.*, 2003; Mohanty *et al.*, 2016). The changes in the simulated yield potential per unit area for the soybean caused by changes in the temperature, CO_2 concentration and rainfall over the period 1980-2010 for the Bhopal region was investigated during 2012-13. It was assumed that these changes could explain the declining or improvement in yield or yield stagnation of soybean crop in Madhya Pradesh.

The soil parameters required to calibrate the model for simulation of soybean growth include: soil bulk density, saturated soil water content, soil water at field capacity and wilting point, organic carbon, ammonical and nitrate nitrogen etc, are presented in Table 1. Other parameters related to the water balance are first stage soil evaporation coefficient (U =6 mm), Second stage soil evaporation coefficient (CONA), runoff curve number (CN2 = 73), whole profile drainage rate coefficients (SWCON = 0.3). The soil considered is a Vertisol with extractable water capacity of 150 mm up to 120 cm depth.

The simulations were performed for a widely cultivated soybean cultivar (JS 335). The crop parameters used for simulation study were those reported by Mohanty *et al.* (2012). The soybean cultivar matures in about 95 to110 days. A soybean plant population of 45 plants m^{-2} at 30-cm row spacing was used throughout the simulation study. Fertilizer to supply 20 kg ha^{-1} N (as urea) to soybean was applied at the time of sowing. This application was considered the "general purpose" nutrient management in the simulation. The other nutrient management practices such as application of phosphorous, potassium and micronutrients are assumed to be optimal for crop growth. There was no attack of insect pests and diseases during crop growing period.

The methodology of assessing the impact of climate change on simulated soybean yield was based on procedure laid out by the coordinated climate-crop modelling pilot team (C3MP) (McDermid *et al.,* 2015). The C3MP methodology generates 99 sensitivity tests that are designed to efficiently sample the uncertainty space in projected temperature, rainfall, and carbon dioxide changes in the 21st century (Fig 1.). Future climate projections were created by utilizing a 'delta' approach, in which the mean monthly changes in important agro-climatic variables were calculated by taking the difference between the Representative Concentration Pathways-8.5 (RCP8.5) climate scenario and simulated baseline conditions. These monthly mean agro-climatic changes, or deltas, were then applied to the daily baseline weather series for each respective month. By analyzing end-of-century (2077-2099) outputs from the global climate model outputs, the upper and lower bounds of each climate variable were derived and presented in Table 2. These ranges include the projected extremes over the majority of agricultural lands (Taylor *et al.,* 2009). Although by the end of the 21st century have CO_2 higher than 900 ppm in representative concentration pathways

(RCP 8.5), while end-of-century period (2077-2099) has a central year CO_2 concentration of 801ppm. Therefore, 900 ppm was taken as the upper bound for CO_2 so that contributed results will remain relevant in the event that more extreme projections become plausible (Ruane *et al.,* 2014).

The ninety-nine sensitivity tests were generated using 30 years of climate data (1980-2010) as to achieve each test's temperature, rainfall and CO_2 concentration range, resulting in 2970 (99 tests × 30 years) yields. The mean yield was predicted using well calibrated and validated APSIM model. To study how climate change affects the yield variability, the coefficient of variation of yield was also calculated. This enables the least-squares fitting of a quadratic crop model emulator for yield (*Y)* and coefficient of variation (*CV)* for any given experimental location as a function of carbon dioxide concentration (CO_2), temperature change (T), and rainfall change (R) to determine coefficients a-k in each of:

$$Y(CO_2, T, P) = a + b(T) + c(T)^2 + d(P) + e(P)^2 + f(CO_2) + g(CO_2)^2 + h(T*P) + i(T*CO_2) + j(P*CO_2) + k(T*P*CO_2) \quad ....(Eq\ 1)$$

$$CV(CO_2, T, P) = a + b(T) + c(T)^2 + d(P) + e(P)^2 + f(CO_2) + g(CO_2)^2 + h(T*P) + i(T*CO_2) + j(P*CO_2) + k(T*P*CO_2) \quad ....(Eq\ 2)$$

The emulator provides for the visualization of each site's sensitivity to the CO_2, temperature and rainfall climate metrics and enables efficient characterization of crop responses to multiple future climate projections. By examining the slope of the emulated response surfaces at the historical baseline climate's location ($\Delta T=0°C$; $\Delta P = 0\%$; $CO_2 = 360$ppm), it is possible to examine the sensitivity of yield to each climate metric. Ruane *et al.,* (2014) has also described that the impacts response surfaces defined by these emulators (statistical representations of models) are a better subject of comparison than the values of specific coefficients.

RESULTS AND DISCUSSION

The effect of climate change could be positive or negative on crop yield depending upon the types of crops, their genotypes and environmental condition. In most of the agricultural crops, increase in temperature decreases the crop yield. Even with minor deviations from the normal weather, the efficiency of extremely applied inputs and food production is seriously impaired. The three dimensional CO_2×T×R showed general decrease in soybean yield under higher temperature, lower rainfall and CO_2 concentration, whereas, increase in yield was observed in cooler, wetter and higher CO_2 environment (Fig 2-4). In particular, an increase in the temperature by 1.5 °C, the grain yield of soybean reduced by 20 per cent. Merely increase or decrease in rainfall did not had much effect on soybean yield, while decreasing the temperature from the current climate by 1°C and increasing the rainfall by more than 10% favoured the soybean yield (Fig 2a). A decrease in rainfall along with an increase in temperature reduced soybean yield give the extent of decease. However, increase in temperature with increase in rainfall also did not favour soybean growth. Increasing the temperature by 1.5 °C along with the increase in rainfall by 50 per cent during soybean growth period reduced the soybean yield by 10 per cent. Beyond 1.5 °C increase in temperature, the increase rainfall did not show any positive impact on soybean yield. Similarly, the CV of the crop yield has been presented in the Fig. 2b which indicated the variation in the data series used for soybean grain yield analysis. The green pattern in the Fig 2b indicated less variability in the mean yield of soybean for that simulation sensitivity tests. Several simulation studies indicated that variation in temperature is more prominent than variation in rainfall. Schlenker and Lobell (2010) showed that impact on maize, sorghum, millet, groundnut, and cassava yield due to temperature changes are much stronger than rainfall changes. Soybean crop in India is also found to be more vulnerable to higher temperature. The thermal stress on the soybean crop at selected sites in India resulted into 12, 18 and 21 per cent decrease in yield under GCMs namely the GFDL, GISS and UKMO, respectively (Mall *et al.,* 2004). Lower yield under high temperature is attributed to shorter life cycles of the crops and its significant impact on leaf ageing or senescence, consequently leads to reduction of the total biomass and grain yields (Deryng *et al.* 2014; Bassu *et al.* 2014).

Further, increase in CO_2 concentration favored soybean growth when the temperature was reduced by 1 degree from the baseline temperature (Fig. 3a). However, with increase in CO_2 the yield reduced by the adverse impact of rise in temperature on crop growth. Even with increasing the temperature by 1 degree and CO_2 concentration to double from the current stage, the yield declined in soybean as high as 15 per cent (Fig. 3a). The variability in the dataset can be seen in the Fig. 3b. Mall *et al.* (2004) used the CROPGRO-soybean model to simulate the impact of climate change on soybean production in India. In their study, all the GCM projected climate change scenarios (at the time of doubling of CO_2 concentrations) predicted decrease in

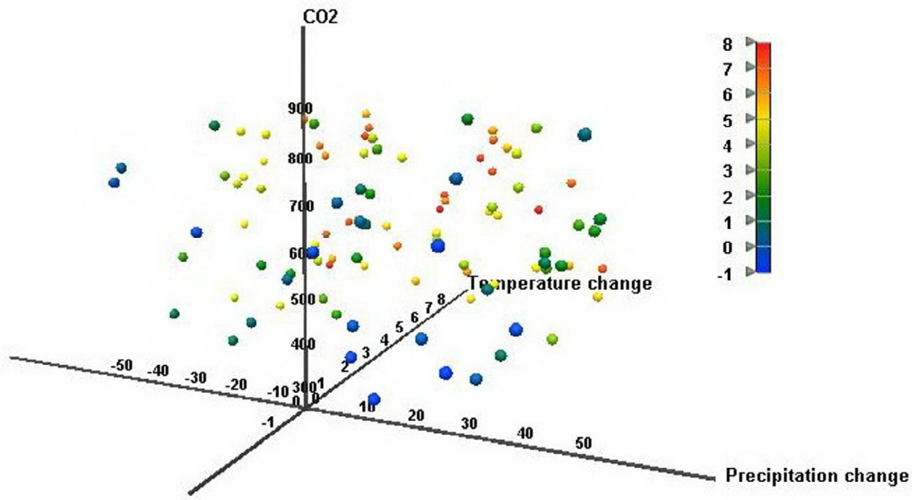

Fig. 1: 3-D representation of ninety-nine sensitivity test following C3MP methodology covering change in carbon dioxide, temperature and rainfall uncertainty space uniformly. (Colour bar indicate the temperature change)

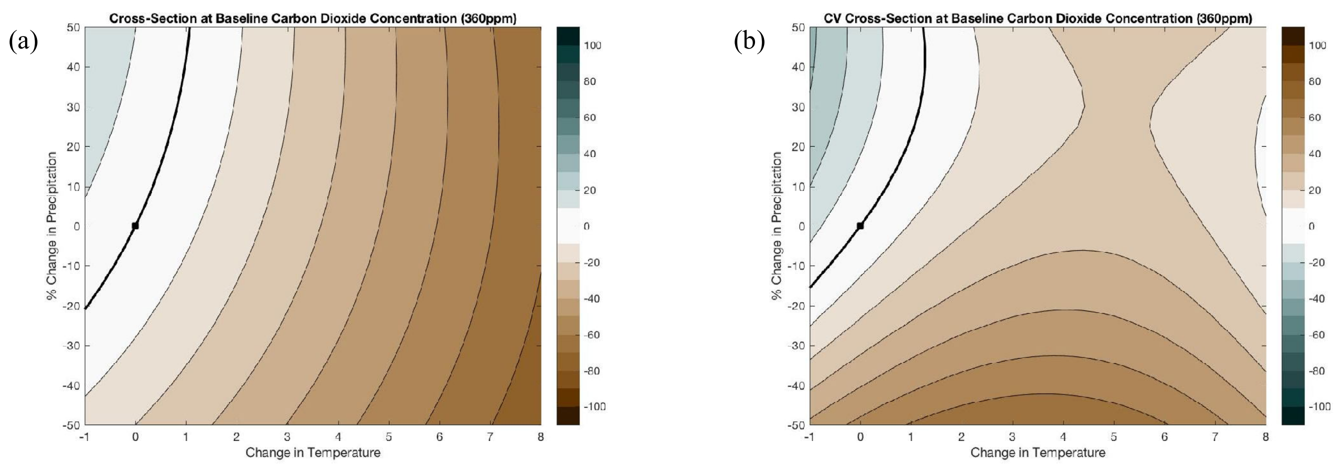

Fig. 2: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in temperature and rainfall at constant CO_2 concentration (360 ppm).

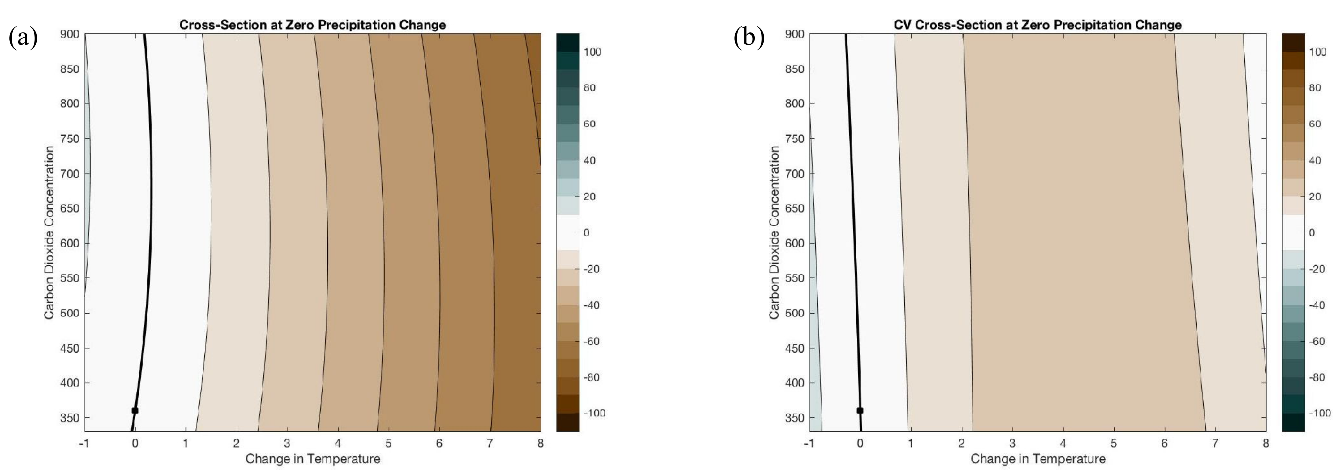

Fig. 3: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in temperature and CO_2 concentration, without changes in rainfall.

Table 1: Soil parametrization of APSIM model for the experimental site.

Soil layercm	BD Mg m^{-3}	DUL m^3 m^{-3}	SAT m^3 m^{-3}	LL 15 m^3 m^{-3}	OC %	pH	NH_4-N mg kg^{-1}	NO_3-N mg kg^{-1}
0-15	1.28	0.39	0.51	0.24	0.49	7.8	1.6	15.0
15-30	1.34	0.38	0.49	0.27	0.47	8.0	1.9	12.0
30-60	1.35	0.39	0.47	0.27	0.46	7.9	1.5	8.0
60-90	1.40	0.40	0.45	0.28	0.43	7.9	1.5	4.5
90-120	1.45	0.41	0.45	0.28	0.41	8.0	0.5	3.5

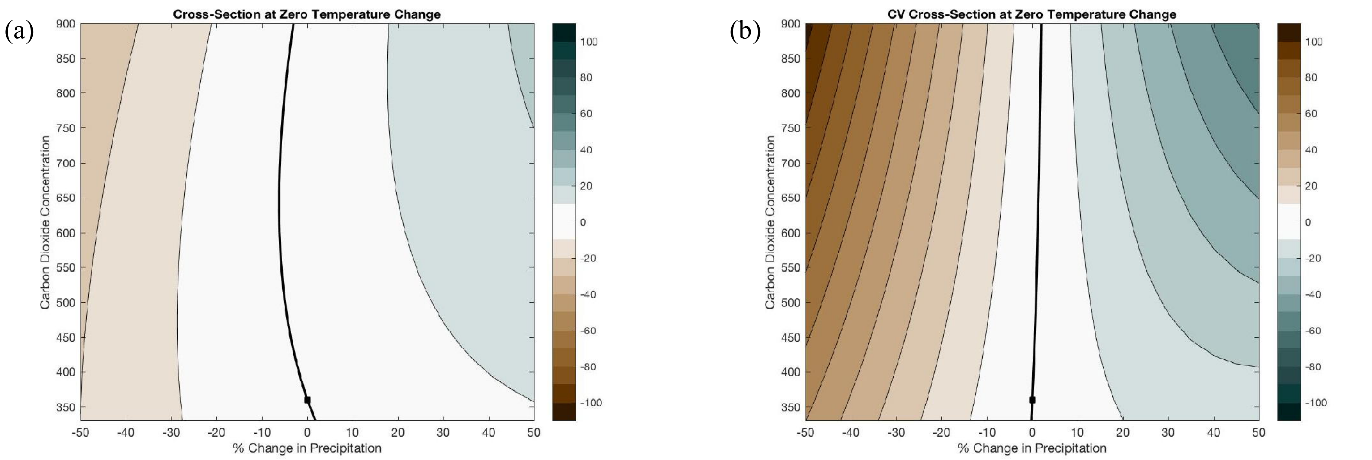

Fig. 4: Simulated (a) soybean grain yield and its (b) coefficient of variation, as affected with changes in CO_2 concentration and rainfall, without changes in temperature.

Table 2: Climate metric ranges for C3MP climate sensitivity experiments.

Climate Metric	Lower bound	Upper bound
T=Temperature change (°C)	-1	+8
P=Rainfall change (%)	-50	+50
CO_2=Carbon Dioxide ppm Concentration	360	900

yields for almost all locations. Mean decline in yields across different scenarios ranged from 14 per cent in Pune (West India) to 23 per cent in Gwalior (Central India). With increase in temperature by 3^0C, there was on an average 7 days' reduction in the growth period of soybean crop. Lal *et al.* (1999) projected 50 per cent increased yield for soybean for a doubling of CO_2 in Central India by using CROPGRO-soybean model. However, a 3°C rise in surface air temperature almost cancels out the positive effects of doubling of carbon dioxide concentration results in reducing the total duration of the crop (and hence productivity) by inducing early flowering and shortening the grain fill period. The effect of climate change scenario of different periods can be positive or negative depending upon the magnitude of change in CO_2 and temperature (Kang *et al,* 2000).

The increase in rainfall usually have positive effects on crop yield. In this study, the simulation results showed that increase in rainfall level to the tune of 18 per cent might not have significant effect on soybean yield. However, with increase in CO_2 level from the current 360 ppm along with increasing the rainfall to 50 per cent, the yield showed a positive trend (Fig. 4a). With increasing the CO_2 level to 750 ppm and rainfall to 50 per cent, the soybean yields increased upto 30 per cent from the current level of production. The coefficient of variation(CV) of the soybean yield data is presented in Fig. 4b. Lal *et al.* (1999) concluded that acute water stress due to prolonged dry spells during monsoon season could be a critical factor for the soybean productivity even under the positive effects of elevated CO_2 in the future.

CONCLUSION

This study revealed that increase in temperature adversely affected the soybean yield. Increase temperature combined with higher rainfall had low impact on soybean yield. However, increase in CO_2 had fertilizing effect on soybean yield but increase in yield was masked by increase in temperature. The variety studied didn't respond to increase in rainfall from the base climate (300 ppm). Increased rainfall (50 per cent) along with increase in CO_2 concentration (750 ppm) favored soybean yield by 30 per cent. However, the findings reported in present investigation depend on the many assumptions built into the crop simulation models, which need to be incorporated in the future studies for better assessment of final yield. However, overall impact of climate change (combined effect) was found negative in our study.

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Response of wheat varieties to heat stress under elevated temperature environments

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ABSTRACT

A field experiment was conducted during winter (*rabi*) season of 2014-15 at IARI, New Delhi to evaluate the response of wheat varieties to heat stress. Three wheat varieties (HD 2967, WR 544 and HD 2985) were grown under ambient and elevated temperature (1.9 to 3.4 °C more than ambient during crop season) condition. Results indicated that the variety WR 544 is highly resistant to heat stress as it exhibited stability of leaf area index (LAI), photosynthesis (Pn), grain yield, harvest index (HI) and test weight under elevated temperature. However, HD 2967 recorded more yield but WR 544 performs better in elevated temperature conditions.

Key words: Wheat, heat stress, leaf area index, photosynthesis, yield

Currently agriculture is facing multi-dimensional challenges including climate change. Projected increases in temperatures and frequency of weather extremes (IPCC ARS, 2014) could significantly constrain wheat production in a future climate. In India, wheat is challenged by climatic risks such as early and terminal heat stress, and unseasonal rainfall. Since wheat is sensitive to high temperature (Ortiz *et al.,* 2008), increase in temperature is a severe threat to wheat production, particularly when it occurs during reproductive and grain-filling phases (Sandhu *et al*, 2016). Heat stress reduces plant photosynthetic capacity through metabolic limitations and oxidative damage to chloroplasts, with concomitant reductions in dry matter accumulation and grain yield (Farooq *et al.,* 2011). Both plant growth and development are affected by temperature (Porter and Moot, 1998).

Several low-cost technologies can reduce the negative impacts of climate change (Easterling *et al.,* 2007). These adaptation strategies include improved varieties (Chapman *et al.* 2012) and improved or altered agronomy (Ingram *et al.,* 2008) along with efficient input use. In wheat, conversion of late sown areas into timely sown areas could significantly improve yield even with the existing varieties in the future (Naresh Kumar *et al.*, 2014). Wheat varieties vary for their duration as well as tolerance to temperature stress. A shorter-duration cultivar is likely to yield less, while the longer duration variety may be exposed to more climatic stresses. Hence, farmers always are in dilemma regarding the choice of variety. In northwest China, farmers mostly introduced longer-duration cultivars to counteract the negative impacts of temperature trend on wheat phenology (He *et al.,* 2015). The majority of previous studies showed that increase in temperature shortened crop growing period, leading to reduced crop productivity (Monzon *et al.,* 2007; Wang *et al.,* 2012). This study was aimed to quantify the response of a long duration and medium duration verities to high temperature. This study is expected to provide scientific basis for the choice of variety in changing climates.

MATERIALS AND METHODS

Field and experimental details

A field experiment was conducted during *rabi* season of 2014-15 at the Research Farm of ICAR- Indian Agricultural Research Institute, New Delhi. Geographically, Delhi is situated between latitude of 28°37' and 28°39' N and longitude of 77°9' and 77°11' E at an altitude of 225.7 meter above mean sea level. It has semi-arid, sub-humid and sub-tropical climate with hot dry summer and severe cold winter. The soil of experimental field is slightly alkaline with low electrical conductivity and is well drained. The soil is sandy loam in texture with pH 7.5 and has about 0.43% soil organic carbon.

Experiment was laid out in a homogenous field with three varieties (HD 2967-long duration variety, WR 544 and

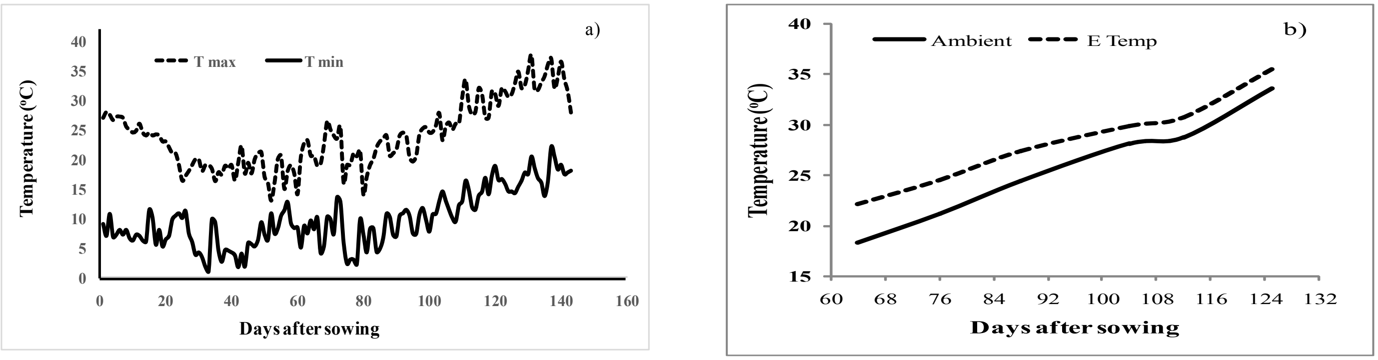

Fig 1: Ambient maximum and minimum temperatures during the crop growing season (2014-15). The temperature inside chamber was 1.9 to 3.7 °C higher than ambient. Figure b shows the ambient and chamber temperature at 11am during the crop growth period (65-124 days).

Table 1: Days to different phenological events in three wheat varieties under ambient and elevated temperature (2014-15)

Varieties	Days to 50% emergence		Days to anthesis		Physiological Maturity	
	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature
HD 2967	8	6	91	82	130	121
WR 544	7	6	86	77	125	116
HD 2985	7	6	83	75	121	110
C.D.(P=0.05)	0.67	NS	0.81	0.91	1.97	1.61
SEM	0.22	0.19	0.27	0.28	0.64	0.55

HD 2985- both of medium duration) in ambient and elevated temperature conditions in four replications. For elevated temperature, the plots were covered with metallic chambers with polythene walls on the top and all four sides to maintain temperature inside the chamber. The dimension of chambers was 5 meter in length and 4 meter in width. Crop was sown on 16 November in 2014. A uniform dose of fertilizers were applied (120N:60P_2O_5:40K_2O) with 50% N applied at the time of sowing, 25% N each at 25 and 45 days after sowing. Total six irrigations were given at all the important physiological growth stages (at pre-sowing, crown root initiation, tillering, flowering, milk and at dough stage) of wheat. The mean maximum temperature during the crop season was 22.9°C while the mean minimum temperature was 9.2°C (Fig 1a). Temperature in chambers was 1.9 to 3.7°C higher than the ambient during crop growth period (Fig 1b). Rainfall during the cop period was 263.6 mm. The mean bright sunshine hours was 4.3 and mean wind speed was 4.5 kmh^{-1}.

Observations on crop:

Observations recorded include dates of phenological events such as 50% seedling emergence, 50% anthesis, and physiological maturity; leaf area index at 15 days interval using plant canopy analyser (LI 2000); gas exchange parameters using infrared gas analyser at various stages of crop; grain and straw yield at harvest; and harvest index and test weight of seed to compare the performance of wheat varieties grown at ambient and elevated temperature. Gas exchange parameters were recorded using a portable photosynthesis system –Infra Red Gas Analyzer (LI-6400XT, LI-COR, USA) at vegetative and reproductive stages. Observations were taken during 9:00 AM to 11:00 AM on flag leaf. The flow rate of input air was set to 300 µmol. s^{-1}. Photosynthatically active radiation was set at 1000 µmol m^{-2} s^{-1} using red and blue light source (6400-40 LCF). Reference air carbon dioxide concentration was kept at ambient level of 400 µmol.mol^{-1}. Readings were logged in when internal CO_2 concentrations attained stability. For each observation, 10 readings were logged in each treatment and then their mean was calculated. Observations on net photosynthesis, transpiration, stomatal conductance, and instantaneous and intrinsic water use efficiency were used for analysis. Grain yield is reported at 14 per cent moisture while the straw yield is on oven dry weight basis. All data were statistically analysed using the SPSS (v16.) and CD was used to compare the means.

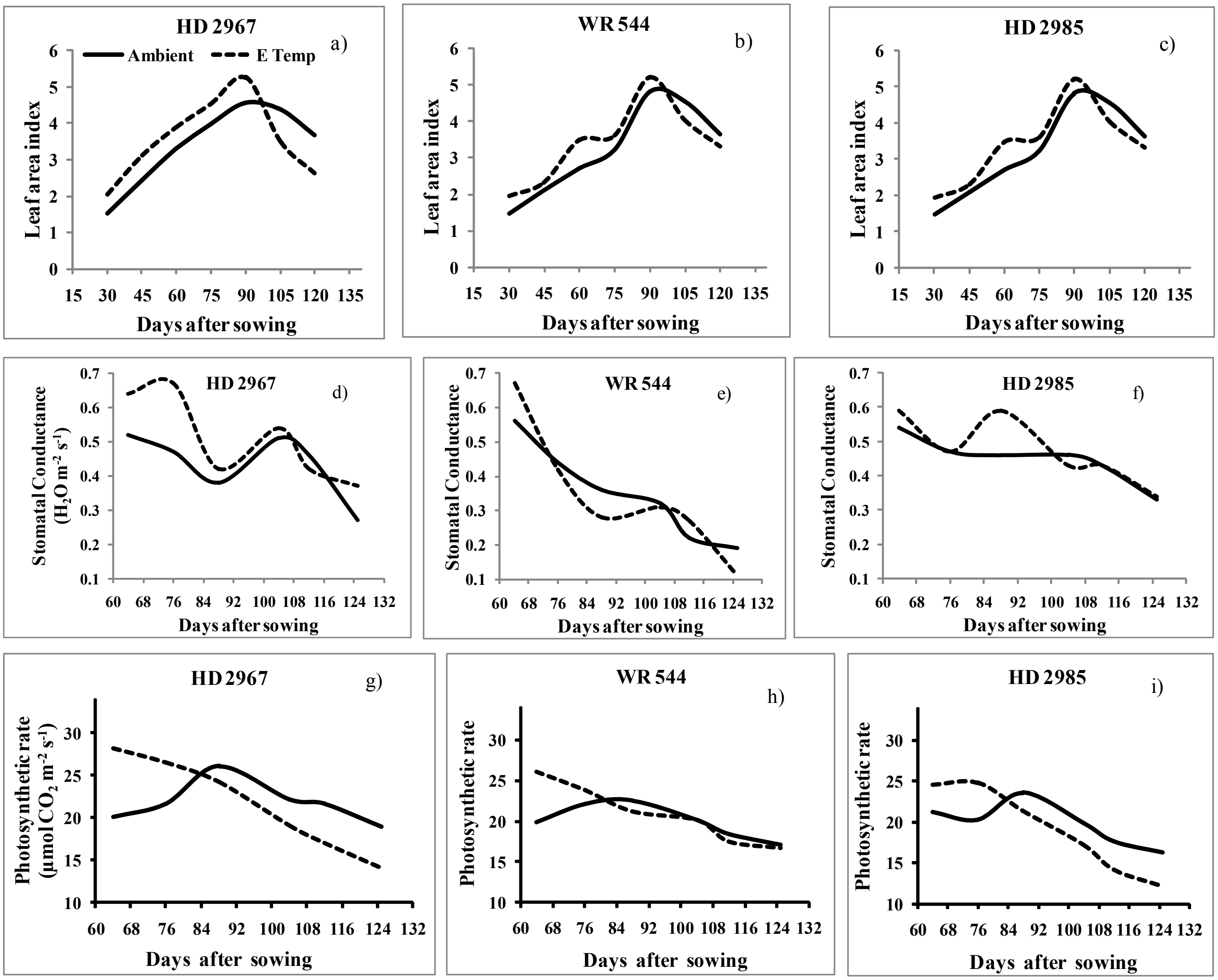

Fig 2: Leaf area index (a-c), stomatal conductance (d-f) and photosynthetic rate (g-i) of three varieties of wheat grown in ambient and elevated temperature conditions (2014-15)

RESULTS AND DISCUSSION

Phenology

Varieties grown in elevated temperature had early anthesis as well as early physiological maturity than those grown under ambient condition (Table 1). The days to emergence and anthesis were more in HD 2967 followed by WR 544 and HD 2985.Days to physiological maturity was more in HD 2967 followed by HD 2985 and WR544. In elevated temperature condition, the percent decrease in days to 50 per cent emergence was more in HD 2967. But percent decrease in days to 50 per cent flowering was almost same for three varieties. Increase in temperature shortened crop growing period leading to reduced crop productivity (Monzon *et al.,* 2007; Wang *et al.,* 2012).

Leaf area index

Under ambient and elevated temperature conditions, leaf area index increased till 90 DAS and thereafter it decreased. Up to anthesis stage, the LAI was more in varieties in elevated temperature than in ambient condition. However, after anthesis, the LAI decreased more rapidly in elevated temperature resulting in lower LAI than in ambient condition. Among the varieties, LAI was more in HD 2967 and WR 544. In elevated temperature, these two varieties had similar LAI up to anthesis, but in post-anthesis period LAI decreased more rapidly in HD 2967 than in WR 544 (Fig. 2 a-c).

Stomatal conductance and photosynthetic rate

Stomatal conductance in general, followed a decreasing trend towards crop maturity and it was higher in elevated temperature conditions (Fig. 2 d-f). In the ambient

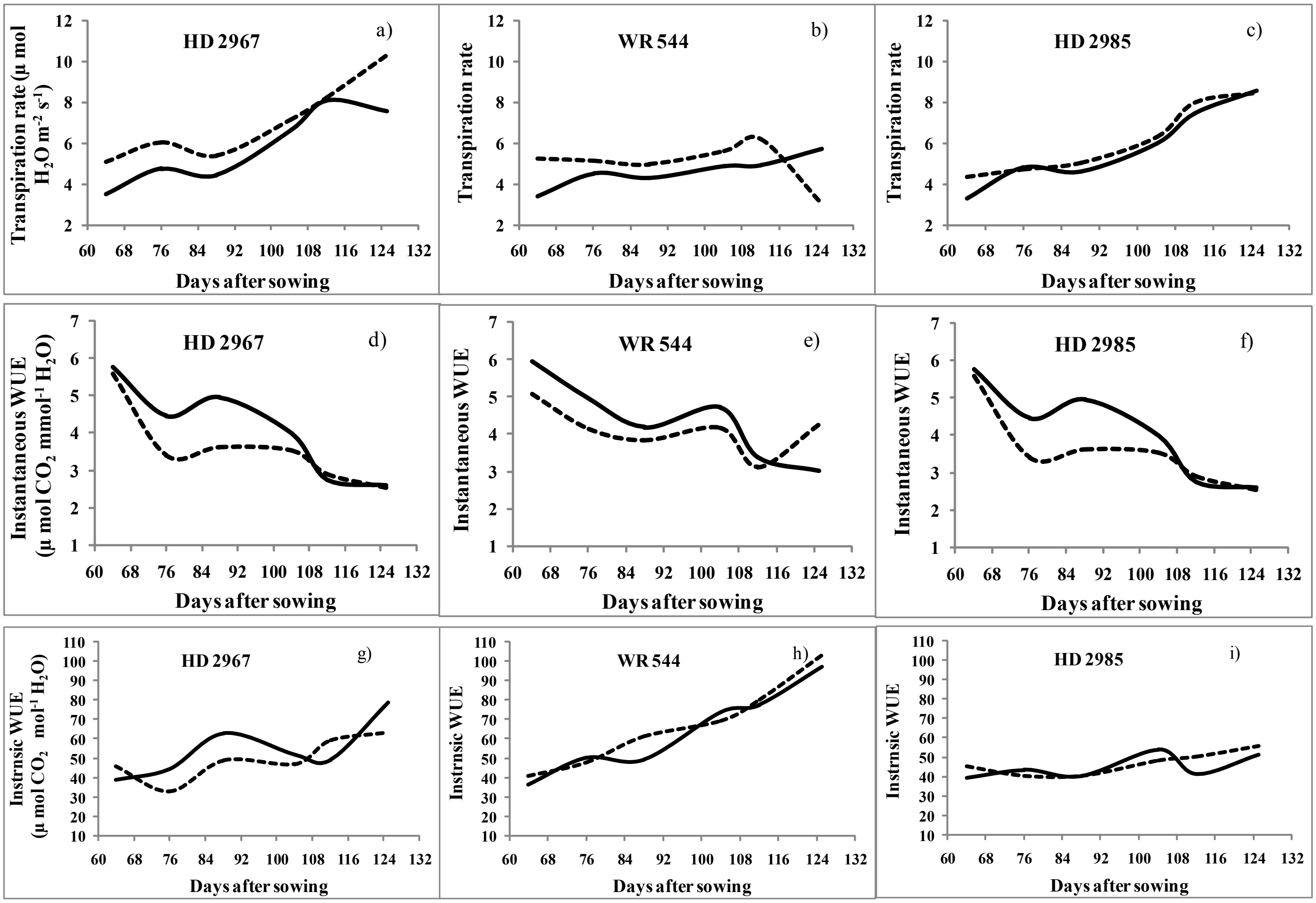

Fig 3: Transpiration rate (a-c), instantaneous water use efficiency (d-f) and intrinsic water use efficiency (g-i) of three varieties of wheat grown in ambient and elevated temperature conditions (2014-15).

condition, photosynthetic rate peaked at 88 days after sowing (DAS) and then declined towards maturity. But in elevated temperature chambers, photosynthetic rate was significantly higher than in ambient grown varieties till 88 DAS in all three varieties. But during grain filling period, the Pn rates declined rapidly and were significantly lower than the ambient in HD 2967 and HD 2985. On the other hand, in WR 544, the Pn rates were almost similar in elevated temperature as well as in ambient condition (Fig 2 g-i). In elevated temperature condition, though HD 2967 had higher Pn rates till 88 DAS, they were significantly higher in WR 544 during grain filling period. After flowering stage the variety WR 544 could maintain the Pn rates in elevated temperature and thus this variety was least affected by heat stress (Fig. 2).High temperature affects photosynthesis (Blum *et al.* 1994) and optimal rates of photosynthesis in wheat are about 25°C (Yamasaki *et al.,* 2002) and they decline as the temperature departs from the optimum. In this experiment, the Pn rates were higher in elevated temperature condition till 88 DAS mainly because the temperature regimes were towards optimum as compared to the ambient. But once the temperatures crossed optimum in elevated temperature condition, Pn rates declined rapidly as compared to the ambient. As mentioned earlier, WR 544 could maintain the Pn rates in elevated temperature condition similar to that of ambient.

Transpiration rate, instantaneous water use efficiency and intrinsic water use efficiency

Transpiration rate was higher in elevated temperature compared to that in ambient condition (Fig. 3 a-c).The instantaneous WUE, calculated after dividing the photosynthetic rate by the transpiration rate (A/E) was higher in ambient condition. The WUE decreased with the progression of crop growth from pre flowering to physiological maturity. Among the varieties, HD 2967 had higher instantaneous WUE till 108 DAS but during the later part of grain filling phase, the WUE was similar in ambient and elevated temperature (Fig 3 d-f). The instantaneous WUE in HD 2985 was almost similar in ambient and elevated

Table 2: Yield, harvest index and test weight of wheat varieties grown in ambient and elevated temperature conditions (2014-15).

Varieties	Grain yield (tha^{-1})		Straw yield (tha^{-1})		Harvest Index (%)		Test weight (g)	
	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature	Ambient	Elevated temperature
HD 2967	5.66	4.16	9.65	8.02	37.00	34.13	40.7	37.5
WR 544	3.80	3.59	7.26	7.01	34.32	33.83	38.6	37.9
HD 2985	3.28	2.58	6.81	5.87	32.51	30.54	35.2	33.0
C.D.(P=0.05)	0.86	0.81	0.98	1.05	0.71	0.59	0.99	0.73
SEM	0.27	0.23	0.32	0.34	0.23	0.19	0.33	0.24

temperature condition. On the other hand, WR 544 maintained higher WUE during later part of grain filling phase. In general, among three varieties in elevated temperature condition, WR 544 had higher WUE.

The intrinsic WUE was calculated after dividing the photosynthetic rate by the stomatal conductance (A/gs). It followed a general increasing trend from vegetative phase to physiological maturity. Though HD 2967 maintained higher intrinsic WUE during in ambient condition during most parts of the growth period, WR 544 and HD 2985 had similar intrinsic WUE in ambient and elevated temperature condition. The intrinsic WUE was higher in WR 544 followed by HD 2967 and HD 2985. Overall results indicate greater efficiency of WR 544 for maintaining LAI, Pn rates and WUE in elevated temperature condition.

Yield and yield components

Elevated temperature caused a reduction in grain and straw yield in all three varieties. Reduction in grain yield was more in HD 2967 (25%), followed by HD 2985 (21%) and WR 544 (6%) as compared to that of ambient grown varieties. Harvest index was reduced more in HD 2967 and reduction was least in WR 544. Test weight was also reduced maximum in HD 2967 (8%), followed by HD 2985 (6%) and WR544 (2%). These results indicated that WR 544 had more stable HI and test weight indicating its stable source-sink balance even in elevated temperature condition (Table 2).

CONCLUSION

The study revealed that wheat varieties differ in their response to elevated temperature. The variety WR 544 is highly resistant to heat stress as it exhibited stability of leaf area index, photosynthetic rate, grain yield, harvest index and test weight in WR 544 grown under elevated temperature. However, HD 2967 outperformed WR 544 under ambient and elevated temperature conditions, despite more yield reduction in HD 2967 in elevated temperature. Hence, it can be concluded that the variety HD 2967 and WR 544 are more suitable in changing climatic conditions of north-west India.

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Impact of aerosol on climate and productivity of rice and wheat crop in Bihar

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ABSTRACT

Interactions among aerosol optical depth (AOD), maximum temperature, minimum temperature, rainfall and solar radiation for different agro-ecological zones of Bihar in different seasons were examined during 2001-2012. There was significant negative correlation between aerosol and maximum temperature, in post monsoon season in zone I and II and in winter season in zone III B. There was significant negative correlation between aerosol and minimum temperature in pre monsoon and winter season in zone II and III A respectively. In monsoon season, there was negative correlation between rainfall and aerosol for all the zones but statistically not significant. There was significant positive correlation between aerosol and rainfall in pre monsoon season. There was significant negative correlation between aerosol and solar radiation in post monsoon season in zone II. There was significant negative correlation between aerosol and rice yield in zone III A and III B and significant positive correlation between aerosol and wheat crop in zone III A. The effect of aerosol on rice yield was predicted to be in the range of -28 to +44 per cent decrease or increase in yield depending on sky condition. Similarly, the wheat yield also depends on the sky condition during the growing season and ranges from -29.4 to +40.9 per cent decrease or increase due to aerosol.

Key words: Aerosol, trend, temperature, rainfall, solar radiation, rice and wheat yield

The importance of dust solar absorption has been recognized as a potential forcing in altering rainfall distribution globally (Miller *et al.*,2004) and more specifically over south Asia (Lau *et al.*, 2006 a). The small droplets limit collision and coalescence, prolonging the lifetime of clouds and inhibiting the growth of cloud drops to raindrops (Rosenfeld *et al.*, 2001). In increasing moisture and buoyancy, hygroscopic aerosol may activate more CCN and increase rainfall. With the growing attention on the potential effects of aerosol radiative forcing on the Indian monsoon rainfall and circulation in recent years (Menon *et al.,* 2002; Ramanathan *et al.*, 2005; Meehl *et al.*, 2008). Rice yield in India and other parts of Asia are positively correlated late in the season, with solar radiation (Stanhill *et al.,* 2001). On the other hand they are negatively correlated with minimum (night time) temperature (Peng *et al.*, 2004). In general, a large sustained increasing aerosol loading trend has been found over Northern India in Indo Gangetic plain area with the analysis of NASA TOMS data in the past two decades (Massie *et al.*, 2004; Bollasina *et al.*, 2008). However in the IGP, especially in Bihar, the aerosol and their climatic effects have been little known despite the heavy pollution in the region. Burning of fossil fuels and biomass have increased aerosol in the Indo-Gangetic plain. Due to multiple effect of aerosol on climate, there is possibility that reduction or increase in aerosol could have positive impact on yield of crops like rice and wheat, which are major crops of the region. Only a few studies have examined the impacts of aerosol on yield aspects in agriculture (Karande *et al* 2012a & b). But no study has been done on seasonal interaction of aerosol and climatic parameters and yield of crops. Wheat yields are more often limited by moisture or temperature than by solar radiation. However, when these conditions are not limiting, yields can be affected by variations in solar radiation receipt (Lomas *et al.*, 1976). Aerosol can affect the flux of solar radiation directly or indirectly (Schwartz *et al.,* 1996).

MATERIAL AND METHODS

Study area

Bihar is located in the alluvial plains of India. The state is situated between 24^0 N and 27^0 N, 83^0 E and 88^0 E with a height of 52 m amsl, It is divided into three agro-ecological zones: zone I (North West alluvial plains), zone II (north east alluvial plains) and zone III (South Bihar alluvial plains). Zone III is further subdivided into categories A and

B. Four different stations were selected representing different zones (Pusa zone I; Purnea zone II; Sabour zone III A; Patna zone III B). Weather data for Pusa and Sabour were collected from 1955-2012 and for Purnea and Patna from 1969-2012. Satellite data of aerosol optical thickness was downloaded from the website of Goddard space, NASA between latitudes for Bihar region for 2001-2012. Productivity data for rice var. Swarna and wheat crop var. HD 2733 were collected from for duration 2001-2012. The interactions among aerosol optical thickness, rainfall variability, yield of rice and wheat crop in each season were determined. Trends of temperature and rainfall based on long term weather data were tested by Mann Kendall test at 5 % level of significance. Trends of aerosol optical thickness were also tested by the same method for 2001-2012. Correlations were examined between aerosol optical thickness and different weather parameters viz. solar radiation, maximum temperature, minimum temperature and rainfall for different seasons for different stations. Correlations were also examined among productivity of rice and wheat crop and aerosol optical thickness for different regions.

Crop model

The generic grain cereal simulation model CERES Version 4.5 (Ritchie *et al.,* 1998) was used to estimate the effect of aerosols on crop yield and has been integrated in the Decision Support System for Agro technology Transfer (DSSAT). For this study, the model was employed to estimate the radiative influence of atmospheric aerosols on crop growth and yield. The model was modified so that RUE was not a longer static variable but was dynamically calculated as a function of the diffuse fraction on each simulation day. The model computes daily CO_2 uptake based on PAR, RUE, LAI, and various water and nutrient stress levels. The standard CERES model assumes that RUE is a constant value for each species of crop and does not change with the diffuse fraction. In order to isolate the influence of aerosols, it was necessary to make sure that plant growth was not limited by water or nutrient availability. Therefore, the model was configured so that the crops never experienced water or nutrient stress. In order to examine the influence of aerosols on crop growth, cumulative daily radiation was estimated for each day of the year using a radiative transfer model that considers the influence of aerosols. The observed daily cumulative radiation in the meteorological files was replaced with the estimated PAR intensity calculated by the radiation model. In addition, the fraction of PAR which is diffuse was added to each day of the meteorological files. In order to estimate the influence of aerosol loadings on crop yields, the recorded cumulative daily radiation values reported in the observed meteorological data set were substituted with values calculated using the National Center for Atmospheric Research (NCAR) Tropospheric Ultraviolet Visible (TUV) radiation model (Madronich, 1993). This model estimates the intensity of solar radiation incident at the surface based on the amount of radiation at the top of the atmosphere taking into account the absorption and scattering of radiation by gases, particles and cloud droplets. The 2-stream mode of this model was used to compute diffuse fractions. The temperature and precipitation data in the measured meteorological data sets were not changed. Several response curves were used in order to estimate the sensitivity of crop growth to the increase in RUE associated with an increasing diffuse fraction. The response curves ranged from no change at all in the base RUE to a doubling of RUE at high diffuse fractions. For each day in the CERES model runs, RUE is calculated as the base RUE plus a percent increase. For each value of AOD, the CERES model was run for each year for which weather data were available. The yields from each of these years were summarized by calculating an average and a standard deviation. This process was repeated for each RUE response curve. The TUV model was used to estimate the change in PAR reaching the surface and the diffuse fraction as AOD increases. Under clear skies, PAR decreases by 30% as AOD is increased to 1.0 from the background level of 0.05. At the same time, the diffuse fraction was increased by over 200%.

RESULTS AND DISCUSSION

Trends in maximum temperature

Trend statistics (Table 2) of maximum temperature indicates that there is significant decreasing trend of annual maximum temperature (-0.008^0 Cy^{-1}) and (-0.012^0 Cy^{-1}) for stations Pusa and Sabour respectively. There is significant increasing trend (0.041^0 C y^{-1}) of maximum temperature in *kharif* season in Purnia whereas decreasing trend (-0.013^0 C y^{-1}) of maximum temperature in *rabi* season in Sabour.

Trends in minimum temperature

Minimum temperature of all the stations Pusa, Purnia, Sabour and Patna has significant increasing trend in *rabi* season (0.022 ^{0}C y^{-1}), (0.081 ^{0}C y^{-1}), (0.026 ^{0}C y^{-1}) and (0.038 ^{0}C y^{-1}) respectively (Table 3). Purnia shows significant increasing trend (0.037 ^{0}C y^{-1}) of minimum temperature in *kharif* season too. Purnia, Sabour and Patna show

Table 1: Selected meteorological stations representing different agro-ecological zones of Bihar

Station	Agro- ecological Zone	Latitude (^{0}N)	Longitude (^{0}E)	Elevation (m)	Weather data
Pusa	I	25.85	85.78	47	1955-2012
Purnea	II	25.98	87.80	53	1969-2012
Sabour	III A	26.10	87.70	37	1955-2012
Patna	III B	25.58	85.25	41	1969-2012

Table 2: Mann Kendall test (Kendall's tau) with trend for maximum temperature

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.031	0.002	-0.115	-0.008	-0.199	-0.008*
Purnea	0.472	0.041*	0.094	0.006	0.244	0.015*
Sabour	0.058	0.003	-0.23	-0.013*	-2.53	-0.012*
Patna	0.100	0.009	-0.169	-0.012	-0.058	-0.003

*Significant at 5%

Table 3: Mann Kendall test (Kendall's tau) with trend for minimum temperature

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.128	0.010	0.210	0.022*	0.174	0.017
Purnea	0.323	0.037*	0.503	0.081*	0.538	0.057*
Sabour	0.012	0	0.44	0.026*	0.345	0.014*
Patna	0.156	0.008	0.322	0.038*	0.36	0.025*

*Significant at 5%

Table 4: Mann Kendall test (Kendall's tau) with trend for rainfall

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Pusa	0.024	0.829	-0.196	-1.471*	-0.013	-0.342
Purnea	-0.047	-2.038	-0.118	-0.945	-0.099	-4.233
Sabour	0.08	1.647	-0.052	-0.316	0.14	3.513
Patna	-0.104	-3.015	-0.085	-0.627	-0.114	-4.506

*Significant at 5%

Table 5: Mann Kendall test (Kendall's tau) with trend for aerosol

Station	*Kharif*		*Rabi*		Annual	
	tau	Trend	tau	Trend	tau	Trend
Zone I	-0.303	-0.01	0.273	0.004	-0.242	-0.002
Zone II	-0.485	-0.008*	0.303	0.009	-0.242	-0.001
Zone III A	-0.303	-0.006	0.394	0.009	0.091	0
Zone III B	-0.091	-0.005	0.152	0.002	-0.091	0.002

*Significant at 5%

Table 6: Correlation coefficient (r) of aerosol and weather parameters in different seasons

	Zone I				Zone II			
	Winter	Pre monsoon	Monsoon	Post monsoon	Winter	Pre monsoon	Monsoon	Post monsoon
Max temp	-0.104	-0.070	-0.427	-0.528*	0.179	-0.367	0.084	-0.442*
Min temp	-0.386	0.482*	0.291	0.010	0.351	-0.596*	-0.199	-0.152
Rainfall	-0.203	0.189	0.005	0.308	-0.414	0.460*	-0.207	0.168
Solar radiation	0.365	-0.227	0.097	-0.203	0.289	-0.476	0.219	-0.540*
	Zone III A				Zone III B			
	Winter	Pre monsoon	Monsoon	Post monsoon	Winter	Pre monsoon	Monsoon	Post monsoon
Max temp	0.030	0.118	0.356	-0.201	-0.440*	-0.162	0.333	-0.039
Min temp	-0.488*	0.326	0.295	-0.021	-0.270	0.148	0.007	-0.059
Rainfall	-0.280	-0.114	-0.023	-0.239	-0.035	0.246	-0.262	-0.477
Solar radiation	0.221	-0.388	0.011	-0.390	0.206	0.019	-0.034	-0.046

*Significant at 5%

Table 7: Correlation coefficient (r) of aerosol and yield of rice and wheat crop in different zones

Crops	Zone I	Zone II	Zone III A	Zone III B
Rice yield	-0.232	-0.188	-0.763**	-0.595*
Wheat yield	0.201	-0.197	0.596*	0.547

*Significant at 5% ** significant at 1 %

significantly increasing trend of annual minimum temperature (0.057 ^{0}C y^{-1}), (0.014 ^{0}C y^{-1}), (0.025 ^{0}C y^{-1}) respectively.

Trends in rainfall

In Pusa, rainfall is decreasing significantly (-1.471 mm y^{-1}) in *rabi* season (Table 4). In all the stations except Sabour, annual rainfall is decreasing but they are statistically non-significant. At Sabour station, there is increasing trend of *kharif* and annual rainfall but statistically non-significant.

Trends of aerosol

There is significant decreasing trend (-0.008) of aerosol in *kharif* season in zone II (Table 5). Though there is also decreasing trend in *kharif* season and in annual mean of aerosol in all the zones and increasing trend in rabi season but statistically not significant.

Interactions among aerosol and weather parameters

There was significant negative correlation between aerosol and maximum temperature, in post monsoon season in zone I and II and in winter season in zone III B (Table 6). There was significant negative correlation between aerosol and minimum temperature in pre monsoon and winter season in zone II and III A respectively. In monsoon season, there was negative correlation between rainfall and aerosol for all the zones but statistically not significant. There was significant positive correlation between aerosol and rainfall in Pre monsoon season and negative correlation in post monsoon season in all the zones but it was statistically significant in zone II only.

Interactions among aerosol and crop yield

There was significant negative correlation between aerosol and rice yield in zone III A and III B. In zone II, there is also negative correlation between aerosol and rice yield but statistically non-significant (Table 7). In case of wheat, there was significant positive correlation with aerosol in zone III A. In zone I and in zone III B also, there was positive correlation between aerosol and wheat crop yield but statistically non-significant.

Impact of aerosol on rice and wheat crop

Under clear sky condition, an increase in aerosol loading results in a substantial increase in the diffuse fraction. For model simulations in which RUE increases in response to the diffuse fraction, the enhanced efficiency associated with increasing aerosol optical depth (AOD) partially or completely offsets the decrease in total photosynthetically active radiation (PAR). For both rice and wheat crops, a greater increase in RUE results in a less negative influence on average yield. Yield for wheat and rice was predicted to decrease linearly if RUE does not change resulting in a maximum reduction of approximately 30 per cent at AOD =

Table 8: Percent change in crop yield as a function of aerosol optical depth and RUE

	Aerosol Optical Depth														
	0.2			0.4			0.6			0.8			1		
	RUE (%)			RUE (%)			RUE (%)			RUE (%)			RUE (%)		
Crops	0	50	100	0	50	100	0	50	100	0	50	100	0	50	100
Rice	-6.0	7.5	17.2	-10.0	13.0	37.3	-16.1	14.3	42.2	-24.0	13.2	44.0	-28	7.7	42
Wheat	-5.6	8.0	20.2	-13.2	13.4	33.4	-16.5	14.1	40.7	-23.4	10.8	40.9	-29.4	8	39.7

1.0 (Table 8). If RUE fluctuates as a function of the diffuse fraction, the predicted influence on wheat and rice yield was positive. If the maximum change in RUE was 50 per cent, the maximum increase in yield was approximately 15 per cent at AOD = 0.5. If DRUE = 100 per cent, the maximum increase was nearly 44 per cent at AOD = 0.8 in case of rice and 41 per cent in wheat crop yield. An increase in the diffuse fraction can increase the amount of photosynthesis occurring in shaded leaves. Aerosol light scattering decreases total PAR at the same time that it increases the diffuse fraction, aerosols are therefore expected to increase RUE in rice and wheat crops (Rochette *et al.* 1996). The increase in RUE is likely to be less at low LAI than in mid-growing season when a crop is fully developed and has multiple canopy layers and a high LAI. Aerosol radiative forcing usually (though not always) has a negative influence on temperature. This can have either a positive or negative influence on plant growth and development depending on the stage of development and if the temperature is above or below the optimum. The decrease in radiation associated with increasing aerosol concentrations also results in less water loss due to soil evaporation and leaf transpiration. The change in mean yield as a function of aerosol optical depth is highly dependent on the radiation use efficiency of the crop. RUE itself is dependent on the fraction of radiation that is diffuse. The amount of increase in RUE seems to be the most important factor in determining the magnitude and in a few cases even the sign of the change in yield. If RUE increases more than 50 per cent over the base value at high diffuse fractions, this increased efficiency frequently offsets the reduction in PAR due to the influence of aerosols, and consequently, yields are predicted to either increase or decrease by less than if the RUE does not change.

CONCLUSION

There was good correlations with weather parameters like maximum temperature, minimum temperature, rainfall and solar radiation. The presence of aerosols in the atmosphere simultaneously decreased PAR and increased the fraction of PAR which is diffuse. Increasing the diffuse fraction tends to increase the radiation use efficiency of a plant. Aerosols both decrease the amount of PAR reaching the surface and increase the diffuse fraction. Using the most likely set of assumptions concerning AOD and DRUE, the influence on rice yields was predicted to be in the range of -28 to +44 per cent decrease or increase depending on sky condition. Similarly, the wheat yield depends on the conditions during the growing season and ranges from -29.4 to +40.9 per cent decrease or increase due to aerosol. The results strongly suggest the need for a more comprehensive study that will examine the indirect influence of aerosols on temperature, evapotranspiration, clouds and precipitation and consequently on water and nutrient stress. It would also be of benefit for future studies to incorporate a canopy model in order to more accurately estimate RUE throughout the simulated growing season and to consider the influence of changes in the solar spectrum induced by aerosol light extinction.

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Thermal utilization and heat use efficiency of sorghum cultivars in middle Indo-Gangetic Plains

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ABSTRACT

A field experiment was carried out during the summer seasons of 2015 and 2016 in clay loamy soil of ICAR Research Complex for Eastern Region, Patna to study the phenology, accumulation of growing degree days (GDD), heliothermal units (HTU), heat use efficiency (HUE), heliothermal use efficiency (HTUE) and performance of five sorghum cultivars including 3 hybrids (CSH 13 ,CSH16 and CSH 30) and 2 varieties (CSV 23 and SPV 462) were grown under two sowing dates *viz.*16th February and 3rd March in split-plot design. For our study purpose and as per package of practices, February 16 is considered as early sowing and March 3 as timely sowing condition. It was observed that GDDs and HTU reduced significantly by 45.9 °C days and 663.6 °C days hr respectively, in early sowing. The sorghum cultivars SPV 462 and CSH 13 accumulated markedly higher GDDs and HTUs. On mean basis, cv. CSH 16 produced significantly higher grain yield (5.51 tha^{-1}) followed by CSH 13 (4.93 t ha^{-1}). The significant reduction in grain yield was recorded in earlier sowing date than the timely sown crop. The phenothermal index gradually increases from emergence to maturity in all the tested cultivars irrespective of sowing date. Sorghum hybrid CSH 16 showed better performance in terms of HUE and HTUE followed by CSH 13 and SPV 462. Varieties giving higher yield, HUE and HTUE are identified under the varying growing environments, so as to suggest the appropriate sowing time of sorghum cultivars in middle the middle Indo-Gangetic Plains.

Key words: Sorghum, cultivars, growing degree days, heat use efficiency, helio-thermal units and sowing dates.

Sorghum (*Sorghum bicolor* L. Moench) ranks third in the major food grain crops in India, whereas it is the fourth important food grain of the world. Millions of the people in Africa and Asia depend on sorghum as the staple food. The crop has potential to compete with maize under good environmental and management condition. Basically sorghum is a tropical crop. It is drought tolerant and is recommended for dry regions. Grain sorghum follows a predictable pattern of growth from planting through the physiological maturity. Temperature is one of the primary micro-climatic factors driving rates of growth. Rate of plant growth and development is dependent upon temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum, and optimum. These values were summarized by Hatfield *et al.* (2011) for a number of different species typical of grain and fruit production. The number of days required for cultivars to reach maturity depends primarily on location, date of planting and tempera-ture. Due to variations in daily minimum and maximum temperatures from year to year and between location, number of days from planting to physiological maturity varies and, is not a good predictor of crop develop-ment. Meteorological indices *viz.* growing degree days (GDD), heliothermal unit (HTU), and photothermal unit (PTU) based on air temperature are used to describe changes in phenological behavior and growth parameters (Paul *et al.,* 2000; Girijesh *et al.,* 2011; Prakash *et al.,* 2015). The temperature based agrometeorological indices provide a reliable prediction for crop development and yield.

Influence of temperature on phenology and yield of crops can be studied under the field condition through accumulated heat unit system (Pandey *et al.,* 2010). Duration of crop/cultivars is a genetic attributes, and is influenced by environmental condition, which varies with location and years in which it is grown because the rate of development is largely influenced by the temperature and photoperiod.

Plants have a definite heat requirement before they attain certain phenophases. A change in temperature during phenolophases of a crop adversely affects the initiation and duration of different phenophases and finally the economic yield. It is therefore, indispensable to have knowledge of the

Table 1: Yield and yield attributes of sorghum cultivars under different thermal environments (Pooled analysis over two seasons)

Treatment	Days to 50 % flowering	Days to maturity	Grain yield ($t\ ha^{-1}$)	Stover yield ($t\ ha^{-1}$)	Biological yield ($t\ ha^{-1}$)
Sowing date					
16 Feb.	63.2	103.2	3.61	18.1	21.7
3 March	75.9	102.5	4.59	20.8	25.4
SEm±	0.4	0.5	0.12	0.4	0.4
CD (P=0.05)	1.1	NS	0.37	1.1	1.3
Cultivars					
CSH 13	74.3	102.5	4.93	22.7	27.6
CSH 16	71.0	102.5	5.51	15.8	21.4
CSH 30	70.5	100.3	2.91	12.6	15.5
CSV 23	62.8	102.3	3.25	27.1	30.3
SPV 462	69.0	106.5	3.89	18.9	22.8
SEm±	0.6	0.7	0.19	0.6	0.7
CD (P=0.05)	1.8	2.2	0.58	1.1	2.0

exact duration of phenophases in a particular environment and their association with yield attributes for achieving the higher yield, hence keeping above in view the present investigation was carried out.

MATERIALS AND METHODS

Field experiment was conducted during the summer seasons of 2015 and 2016 in the experimental farm of ICAR Research Complex for Eastern Region, Patna (25^0 30'N latitude, 85^0 15'E longitude and 52 m above mean sea level). The treatments comprised of two dates of sowing *viz.* 16th February and 3rd March, in main plot and five grain sorghum cultivars including three hybrids and two inbred as sub-plot were replicated thrice in a split plot design. Soil of experimental site (0-15 cm) was clay loam in texture (23.36% sand, 39.64% silt and 37% clay), low in organic carbon (0.47%), available nitrogen (213 kg N ha^{-1}) and medium in phosphorus (19.7 kg P ha^{-1}) and high in potassium (436 kg K ha^{-1}) and neutral in soil reaction (pH 7.43). The bulk density of experimental field was 1.46 g cm^{-3}. The recommended dose of fertilizers i.e. 80 kg N, 40 kg P_2O_5 and 40 kg K_2O ha^{-1} were applied for grain sorghum for the region. Phosphorus as di-ammonium phosphate (DAP) and potassium as muriate of potash (MOP) were applied as basal on the day of planting. Nitrogen as urea were applied in 2 splits, 50 per cent at sowing as basal application and remaining at 35 days after sowing (DAS). Three irrigations were given during the cropping period as per critical stages of crop. Other cultural operations and plant protection measures were followed as per the recommendations contained in package of practices. Meteorological data were recorded from Agrometeorological Observatory, ICAR RCER, Patna.. The grain, stover and biological yields were recorded as per treatments and expressed in t ha^{-1}.

Growing degree days (GDD), heliothermal units (HTU), phenothermal index (PTI), heat use efficiency (HUE), and heliothermal use efficiency were computed using the daily meteorological data. The base temperature of 10 °C was used for computation of GDD on daily basis (Leong and Ong, 1983). Agro-meteorological indices were computed for different phenophases of crop (emergence, three leaf visible stage, tillering, panicle initiation stage and physiological maturity) by adopting the procedure laid out by Rajput (1980).

Data were analyzed with analysis of variance (ANOVA) as suggested by Gomez and Gomez (1984).Treatments was compared by computing the F-test. The significant differences between treatments were compared pare wise by critical difference at the 5 per cent level of probability.

RESULT AND DISCUSSION

Phenology

In general attributes of sorghum cultivars were markedly influenced with sowing date (Table 1). The 16th February sown crop significantly reduced the number of

Table 2: Accumulated GDD (°C days), HTU (°C days hr) and PTI (°C days day^{-1}) during different phenophases of sorghum cultivars as affected by various treatment (Pooled analysis over two seasons)

Treatment	Emergence			Three leaf visible stage			Max. tillering Stage			Panicle initiation stage			Maturity		
	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI	GDD	HTU	PTI
Sowing dates															
16 Feb.	73.2	473.6	12.4	132.4	858.4	11.4	868.0	5821.0	17.0	1147.8	7853.4	17.4	1934.6	11997.2	22.2
3 March	74.4	386.4	14.0	205.2	1303.2	16.3	1031.8	7611.5	17.6	1275.8	8839.2	18.4	1980.5	12660.8	23.2
SEm±	0.9	4.4	0.2	2.0	11.9	0.1	11.4	72.2	0.2	14.5	87.9	0.2	12.4	130.3	0.2
CD (P=0.05)	NS	13.2	0.5	6.1	35.7	0.4	34.0	216.1	0.5	43.4	263.1	0.5	37.1	390.1	0.7
Varieties															
CSH 13	70.0	378.0	12.5	153.0	977.5	14.0	953.0	7206.0	16.5	1238.5	8891.9	19.5	1962.5	12478.5	23.0
CSH 16	74.5	485.5	11.5	170.0	1083.5	13.0	970.5	6723.0	17.5	1215.5	8446.0	18.5	1911.1	12274.4	22.0
CSH 30	70.4	358.5	14.4	159.5	995.5	12.9	840.0	5822.4	16.0	1166.5	7828.5	20.5	1857.1	12069.5	21.5
CSV 23	67.0	405.0	11.5	160.0	1041.5	15.5	932.0	6302.5	18.5	1105.5	7634.5	10.5	1881.8	11862.0	24.5
SPV 462	87.0	523.0	16.0	201.5	1306.0	14.0	1054.0	7527.5	18.0	1333.0	8930.4	20.5	2175.1	12969.5	22.5
SEm±	1.4	7.0	0.3	3.2	18.8	0.2	18.0	114.11	0.3	22.9	138.9	0.3	19.6	206.	0.4
CD (P=0.05)	4.3	20.8	0.5	9.6	56.4	0.7	53.8	341.6	0.8	68.7	415.9	0.9	58.7	616.7	1.1

days required for 50 per cent flowering (63.2) compared to 3rd March sown crop (75.9) but reverse trend was recorded in case of days to maturity. This might be due to the fact that sowing time determines time available for vegetative phase before onset of flowering, which is mainly influenced by the photoperiod.

Days to 50 per cent flowering and days to maturity differed significantly among the sorghum cultivars. In general, varieties flowered earlier (65.9 days) than hybrids (71days). But the reverse trend was followed in maturity, whereas the hybrids took lesser duration (102 days) compared to varieties (105 days). The variation in phenology of sorghum cultivars was also reported by Rao *et al*. (2013).

Yield attributes

The yield parameters of sorghum cultivars markedly influenced with sowing time (Table 3). Grain and stover yields of sorghum cultivars were significantly higher with 3rd March sown crop (4.59 t ha^{-1}) and respective increase was 27.2 per cent over 16th February sowing. Higher seed yield was realized in case of 3rd March sown crop because of higher growth and yield attributed which lead to higher yield of the respective treatments. Under early sown conditions of 16th February, however plants could not accumulate the sufficient photosynthates due to poor vegetative growth (Mishra *et al*. 2017). Azrag and Dagash (2015) reported that sowing date had greater effect on yield than the cultivar.

Grain and stover yield differed significantly among the sorghum cultivars. The sorghum hybrid 'CSH 16' recorded significantly higher grain yield (5.51 t ha^{-1}) followed by 'CSH 13' (4.93 t ha^{-1}) and the lowest with 'CSH 30' (2.91 t ha^{-1}). Among varieties, 'SPV 462' (3.89 t ha^{-1}) recorded significantly higher yield followed by 'CSV 23' (3.25 t ha^{-1}). On mean basis, hybrids produced 24.65 per cent higher grain yield over the varieties. This might be due to more growth attributes like more plant population, no of green leaves, dry matter and leaf area was recorded more with the respective treatments (Kumar *et al*., 2015a, b; Kumar and Bohra, 2014; Kumar *et al*., 2016 and Mishra *et al*., 2017).

Agrometeorological indices

The agrometeorological indices (GDD, HTU and PTI) during different phenophases of sorghum are presented in Table 2. The February 16 sown crop took longer duration for maturity than the timely sown (March 3) crop in all the cultivars due to lower temperature in month of February, crop took more days to fulfill the thermal requirement. The total accumulated GDD and HTU during the maximum

Table 3: Heat use efficiency (HUE) and heliothermal use efficiency (HTUE) of sorghum cultivars as affected by various treatments (Pooled analysis over two seasons)

Treatment	HUE (kg ha^{-1}°C day)			HTUE (kg ha^{-1} °C day hr)		
	Grain yield	Stover yield	Biological yield	Grain yield	Stover yield	Biological yield
Sowing date						
16 Feb	1.93	9.67	11.60	0.31	1.53	1.84
3 March	2.29	10.72	12.67	0.36	1.68	1.99
SEm±	0.03	0.14	0.17	0.004	0.02	0.03
CD (P=0.05)	0.08	0.43	0.50	0.01	0.06	0.08
Cultivars						
CSH-13	2.55	11.73	14.27	0.39	1.84	2.25
CSH-16	2.86	8.24	11.11	0.45	1.30	1.75
CSH-30	1.54	6.67	8.21	0.24	1.05	1.29
CSV-23	1.68	14.13	15.82	0.27	2.23	2.49
SPV-462	1.94	10.20	12.16	0.31	1.63	1.80
SEm±	0.04	0.23	0.26	0.007	0.03	0.04
CD (P=0.05)	0.13	0.68	0.78	0.02	0.11	0.12

vegetative stage of the crop decreased from 868 °C days and 5821 °C days' hr under Feb. 16 sowing to 1031 and 7611 under timely sowing on March 3, respectively. March 3 sown crop accumulated more heat unit (1980.5 °C days) to reach maturity followed by February 16 (1934.6 °C days). Fifteen days delay in sowing from February 16 (early sown) to March 3 (timely sown) increased the accumulated heat units and helio-thermal units by 45.9 °C days and 663.6 °C days' hr, respectively. Among the cultivars, SPV 462 had higher heat units (2175.1 °C days) and helio-thermal units (12969.5 °C days hr), which might be due to significantly higher number of days taken to maturity followed by CSH 13 (1962.5 °C days and 12478.5 °C days hr). Phenothermal index was highest at maturity (Table 1), the value of which was significantly higher (23.2 °C) in timely sown crop. Among different cultivars, PTI values in 'CSV 23' and 'CSH 16' were significantly higher than 'CSH 13' and 'CSH 16'. This might be due to better growing conditions such as temperature, light, humidity and rainfall to fully exploit genetic potentiality of crop (Bahar *et al*., 2015).

Heat use efficiency and heliothermal use efficiency

At maturity, HUE for grain and straw production was significantly higher (2.29 and 10.7) for March 3 sown crop as compared to February 16 (1.93 and 9.67) sown crop (Table 2).

Among cultivars, CSH 16 had significantly higher heat use efficiency (2.86) followed by CSH 13 (2.55), SPV 462 (1.94), CSV 23 (1.68) and CSH 30 (1.54) for grain production, whereas, CSV 23 had significantly better HUE (14.13) for straw production followed by CSH 13 (11.73), SPV 462 (10.20), CSH 16 (8.24) and CSH 30 (6.67). Helio-thermal use efficiency for grain and straw was found maximum 0.31 and 1.53, respectively for 3rd March sown crops. In case of cultivars, CSH 16 and CSV 23 had highest helio-thermal use efficiency 0.45 and 2.23, respectively for grain and straw production. The minimum heliothermal use efficiency was found in CSH 30 for grain as well as straw production. Higher HUE and HTUE in timely sown could be attributed to the highest grain and straw yield. As the temperature was optimum throughout growing period crop utilized heat more efficiently and increased biological activity that confirm higher yield. Similar relationship was expressed by Thavaprakash *et al*. (2007).

CONCLUSIONS

Based on the above findings, it may be concluded that sorghum cultivar CSH 16 produced higher grain yield (5.51 tha^{-1}) followed by CSH 13(4.93 t ha^{-1}), SPV 462 (3.89 t ha^{-1}), CSV 23 (3.25 t ha^{-1}) and CSH (2.91 t ha^{-1}). On an average, timely sown cultivars produced the maximum grain. The cultivar CSH 16 showed stable yield in almost both the sowing dates and performing overall best in terms of utilization of HUE and HTUE. The growing degree day, helio-thermal units and phenothermal index for entire crop growing period decreased with early sowing. This study also indicated that change in microclimate due to different sowing time is reflected in individual phenological stage. Differences in agro-meteorological indices for various phenological stages indicated that accumulated temperature can be utilized for dry biomass and crop yield forecast.

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Agronomic measures to improve thermal energy utilization by *spring* sunflower (*Helianthus annuus* L.)

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ABSTRACT

Investigations were conducted to study the thermal energy utilization by sunflower during *spring* 2014 and 2015 at Punjab Agricultural University, Ludhiana, Punjab, India. Experiments were laid out with three sowing dates (January 20, February 10 and March 2), two intra rowspacing (30 and 24 cm) and four nitrogen doses (0, 45, 60 and 75 kg ha^{-1}). The results indicated that early sowing and application ofnitrogen significantly increased number of days to attain physiological maturity. The thermal units required to attain various phenological stages also increased progressively as the sowing was delayed. However, effect of sowing date was not conspicuous onaccumulated growing degree days (AGDD) to attain physiological maturity. Widely sown crop required slightly more AGDD than closely sown for attaining physiological maturity. Application of nitrogen also increased the AGDD. Heat use efficiency followed the descending order with each successive delay in sowing.Seed filling duration had highly significant ($P<0.01$) positive correlation and regression with seed yield, indicating that with each unit increase in seed filling duration, seed yield increased by 91.3 units.

Key words: GDD, Helianthus annuus., HUE, Sunflower

The ability of the crop to utilize heat energy for dry matter accumulation is determined by environmental conditions in addition to genetic factors (Rao*et al.,* 1999). Agronomic practices such as sowing time, plant spacing and fertilizer requirement are the important factors influencing the crop growth and yield. Coinciding the crop phenology with favorable environment by selecting the appropriate sowing time is crucial for attaining higher yield. Sowing date is thus, an important non-monetary input that can be adjusted to avail the congenial environment. An appropriate plant stand helps in harnessing the renewable resources in an efficient manner. Maintenance of optimum plant population is therefore, important for achieving high yield of all crops in general and non-tillering /branching crops such as sunflower in particular. Nitrogen is the most important nutrient for plants which increase the total biomass production, yield components and yield as plant metabolic processes need proteins to support vegetative and reproductive growth of crop. Optimum nitrogen nutrition results in rapid leaf area development, prolongs life of leaves, improves leaf area duration and overall crop assimilation, thus leading to yield enhancement (Nasim *et al.,* 2011). Nitrogen is also known to alter the phasic development of crop by maintaining the required nutritional status of the plant and by altering the rate of dry matter accumulation (Copeland and Mcdonald., 1995).

Agronomic practices cause variation in the thermal energy utilization by altering the crop growth and development. Growing degree days (GDD),which determine occurrence of various phenological events in the life cycle of a plant, is the most common agro-climatic index used to estimate phenological development of a plant (Gouri*et al.*, 2005, Bonhomme 2000). Temperature, solar radiation and sunshine duration are major weather variables having significant influence on phenological, physiological and morphological expression of sunflower (Zheljazkov*et al.,* 2009). Nutritional status of plant is another important factor as floral induction in many crop is highly dependent on dry matter accumulation, rate of which is governed by availability of essential nutrients (Copeland and Mcdonald., 1995.). Keeping these in view, present investigations were conducted to study thermal energy utilization by *spring* sunflower under variable sowing times, intra row spacing's and N supply.

MATERIALS AND METHODS

The field experiments were conducted during *spring* 2014 and 2015 at the Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, (30°56' N latitude, 75°52' E longitude and an elevation of

Table 1: Effect of sowing dates, intra row spacing and N dose on phenology of sunflower hybrid PSH 996 (Mean of two years ± SD)

Treatment	Days taken for attainment of						
	Star bud stage	Ray floret stage	Flower initiation	50 % flowering	100 % flowering	Seed filling stage	Physiological maturity
Sowing date							
Jan., 20	60.7± 0.6	70.8± 0.8	74.4± 1.0	79.8± 2.7	85.2± 3.6	91.3± 3.4	116.3± 4.9
Feb., 10	53.2± 0.8	63.8± 1.4	67.2± 1.6	70.7± 1.1	75.2± 2.3	80.6± 2.5	102.2± 5.0
March,2	44.9± 1.3	55.0± 0.3	58.3± 0.5	61.3± 0.4	65.8± 0.5	71.1± 1.2	89.8± 3.2
Intra row spacing (cm)							
30 cm	53.2± 0.4	63.4± 0.5	66.8± 0.5	70.7± 0.7	75.5± 2.1	81.3± 2.5	103.2± 4.4
24 cm	52.8± 0.4	63.0± 0.8	66.5± 0.9	70.5± 1.6	75.2± 2.1	80.8± 2.2	102.3± 4.3
N doses (kg ha^{-1})							
0	51.6± 0.1	64.5± 1.2	67.9± 0.0	72.7± 0.8	77.3± 2.3	83.1± 2.3	100.0± 4.2
45	52.6± 0.4	62.4± 0.3	66.0± 0.1	70.1± 0.8	74.8± 2.1	80.4± 2.3	102.7± 4.2
60	53.4± 0.5	62.7± 0.3	65.9± 0.7	70.0± 1.3	74.9± 1.6	80.4± 1.9	103.7± 4.5
75	54.2± 0.3	63.2± 1.0	66.1± 1.3	70.2± 1.0	74.5± 2.5	80.2± 3.0	104.6± 4.5

247 metres above the mean sea level), India. Ludhiana has sub-tropical and semi-arid climate with cold winters and hot-dry summers. Data on rainfall, maximum and minimum temperatures during the study period were collected from agro–meteorological observatory of PAU, Ludhiana, situated at a distance of 300 metre from the experimental site.

The field experiment was laid out in factorial split plot design with 24 treatment combinations consisting of three sowing dates (D_1-January 20, D_2-February 10 and D_3-March 2) and two intra row spacing's(S_1-30 cm and S_2-24 cm) in main plots and four nitrogen doses (N_0-0, N_{45}-45, N_{60}-60, N_{75}-75 kg ha^{-1}) in sub plots. Sunflower hybrid PSH 996 was sown as per treatmentsreplicated thriceby dibbling 3 seeds per hillat row spacing of 60 cm. One plant per hill was maintained after crop establishment denoted by 2- 4 leaf stage. Phosphorous @ 30 kg P_2O_5 ha^{-1}and potassium @ 30 kg K_2O ha^{-1} were applied at sowing. Nitrogenwas applied as per treatments through urea in two splits, half as basal and half at thinning (3 weeks after sowing). Irrigations were applied as per crop requirement. Earthing up was done 6-7 weeks after sowing to prevent crop lodging. Insecticide chlorpyriphos 20 EC @ 2.5 l ha^{-1}was sprayed at bud formation and 50% flowering stages to control semi looper and head borer. Bird damage was prevented by erecting nylon net over the field ataheight of 2.5 metre. Observations on appearance of various phenological stages viz.star bud, ray floret opening, commencement of flowering, 50 per cent flowering, 100 per cent flowering, seed filling and physiological maturity were recorded by taking daily visual observations from each experimental unit.

Thermal indices viz. growing degree days and heat use efficiency were computed by using crop phenology and meteorological data obtained from School of Climate Change and Agricultural Meteorology, PAU, Ludhiana. Growing degree days (GDD) were determined by "Remainder index" method as per Nuttonson (1955) using a base temperature of 4.0°C as suggested by Villalobos *et al* (1996). GDD were accumulated from the date of sowing to date of attainment of particular phenophase. Heat use efficiency (HUE) for seed as well as total dry matter was computed by dividing the dry matter accumulation or seed yield with accumulated GDD and expressed as kg ha$^{-1°}$C^{-1} day hr. Correlation and regression studies were done using SAS 9.3.

RESULTS AND DISCUSSION

Crop phenology

Delayed sowing caused progressive decrease in number of days taken for attainment of different growth stages viz. star bud, ray floret opening, flower initiation, 50 per cent flowering, 100 per cent flowering, seed filling and physiological maturity and also resulted in reduction in the duration of flowering and seed filling (Table 1). Early sown crop had longest seed filling and reproductive phases. The more number of days taken for appearance of various pheno-

Table 2: Effect of sowing dates, intra row spacing and N dose on duration of different stages, accumulated growing degree days (AGDD) for attainment of various phenophases and heat use efficiency (HUE) of sunflower hybrid PSH 996 (Mean of two years ± SD)

Treatment	AGDD (˚C day hrs) to attain..............stage							HUE (kg ha^{-1} ˚C day^{-1})	
	Star bud	Ray floret	Flower initiation	50% flowering	100% flowering	Seed filling	Physiological maturity	Seed	Stalk
Sowing date									
Jan., 20	698.6±23.9	180.6±1.8	64.2±0.7	98.3±23.3	108.7±22.0	130.2±9.6	639.0±23.3	1.57± 0.09	1.06± 0.11
Feb., 10	744.1±35.1	203.5±7.4	68.1±1.5	75.0±17.7	110.5±27.0	139.6±6.8	556.9±57.6	1.41± 0.06	0.87± 0.04
March,2	736.5±31.8	221.4±4.1	81.5±5.5	81.7±8.8	117.2±26.4	138.4±12.3	518.7±68.9	1.31± 0.04	0.74± 0.05
Intra row spacing (cm)									
30 cm	730.7±29.6	200.9±1.8	72.2±6.1	82.8±1.3	112.6±37.3	140.3±5.7	573.4±35.4	1.35± 0.06	0.87± 0.06
24 cm	722.1±31.0	202.8±7.2	70.3±0.8	87.2±13.5	111.7±13.0	131.9±0.6	569.5±57.8	1.51± 0.07	0.91± 0.06
N doses (kg ha^{-1})									
0	717.9V3.5	234.7±9.5	84.1±12.2	89.3±1.0	114.6±34.4	143.4±9.1	461.8±72.3	1.01± 0.08	0.70± 0.12
45	713.8±35.3	199.5±1.3	72.0±9.5	91.1±14.2	105.5±32.0	136.2±8.3	580.2±29.1	1.34± 0.05	0.88± 0.07
60	731.1±47.2	196.4±12.7	65.3±9.1	88.7±4.3	109.2±15.5	130.7±0.1	613.9±55.6	1.62± 0.09	0.98± 0.04
75	748.8±35.2	176.9±13.2	63.6±2.3	70.9±11.0	119.4±18.7	134.0±13.5	630.3±29.5	1.74± 0.01	1.00± 0.03

phases in earlier sown crop as compared to later sown crop might be due to comparatively low temperature conditions prevailing during the corresponding growth stages of earlier sown crop. Similarly, high temperature and comparatively low relative humidity (%) during seed filling stage of later sown crop (March 2) forced the crop to attain maturity quickly. Ritche and Ne Smith (1991) reported that rate of plant development is temperature driven and all physiological or morphological developments occurring in plant are markedly influenced by temperature. Reduced growth period under late sowing has also been reported by Kingra*et al.,* (2007). Variation in intra row spacing did not cause variation in number of days to attain various pheno-phases except seed filling and physiological maturity stages. Application of nitrogen also had effect on phasic development of sunflower (Table 1). The control treatment (o kg N ha^{-1}) took lesser number of days to attain star bud stage. Application of each higher dose of nitrogen progressively enhanced number of days to reach star bud stage. However, to attain other pheonological stages viz. ray floret opening, flower initiation, 50% flowering, 100 per cent flowering and seed filling stage followed a reverse trend where control treatment took more number of days than N application treatments, which indicate that N fertilization tended to advance the crop development. However, the numbers of days to reach physiological maturity were higher in the treatment receiving 75 kg N ha^{-1} and it decreased consistently under lower doses of N fertilizer. The duration of seed filling also registered consistent increase due to application of successive higher N dose. Application of N prolonged the crop duration by delaying crop maturity as nitrogen induce vegetative and generative growth and prevent premature senescence, thereby potentially enhancing the metabolic processes of plant and lengthening its life cycle, which ultimately resulted in significant increase in seed filling duration.

Growing degree days (GDD)

The late sown crop (March 2) accumulated more growing degree days (GDD) than earlier sown crop (January 20 and February 10) while the differences between February 10 and March 2 were very narrow up to flower initiation stage but as the crop stage progressed to 50 per cent and 100 per cent flowering, the differences between January 20 and February 10 were narrowed down and March 2 sown crop continued to accumulate more GDD than earlier sown crop (Table 2). Similarly at seed filling stage, progressive increase in accumulated GDD was observed due to delayed sowing. Contrary to this, earliest sown and late sown crop accumulated almost same number of GDD for attainment of physiological maturity. However, for attainment of all other phenophases, the later sown crop (March 2) accumulated 5-9.5 per cent more GDD than that of earliest sown crop indicating higher

Table 3: Correlation and regression coefficients between various parameters recorded/computed on the basis of mean data of two years

Variable	Correlation (r)	Regression (b)	Coefficient of determination (r^2)
AGDD at seed filling with seed yield	-0.73**	-5.919**	0.533
AGDD at maturity with seed yield	0.78**	4.44**	0.621
Seed filling duration with seed yield	0.96**	91.32**	0.920
GDD accumulated during seed filling duration with seed yield	0.995**	3.96**	0.913

** Significant at 1% level

AGDD by earliest sown crop during seed filling stage. As sunflower is a photo and thermo-insenstive crop, thus transition of crop from one pheno-phase to another seems to be largely governed by dry matter accumulation by the plant, which in turn is governed by prevailing temperature and nutritional status of the crop plant. The increase in number of GDD accumulation with delay in sowing for attaining a particular stage might be due to the high temperature during the growth period of late sown crop. Though the earlier sown crop took more number of days for attaining physiological maturity but accumulated almost equal number of heat units due to the fact that low temperature prevailed at all phenological stages in general and during early phases of crop growth in particular. Increase in number of GDD accumulation with delayed sowing has also been reported by Kingra *et al.,* (2007). Wider sown crop accumulated more number of GDD for attainment of all pheno-phases (Table 2). The less number of accumulated GDD under dense sowing can be ascribed to the reduction in duration of pheno-phases due to intra row competition, which might have caused stress to the crop for early completion of life cycle. It is further evident from the data in Table 2 that application of 75 kg N ha^{-1} registered the highest number of accumulated GDD for attainment of star bud and physiological maturity stages. However, for attainment of all other phenol-phases, the control (0 kg N ha^{-1}) treatment accumulated more number of heat units (Table 2). It is evident that well fertilized crop maintained higher crop growth rate and completed the particular pheno-phase earlier than poorly-fed crop. More number of heat units accumulated up to star bud and physiological maturity stages due to 75 kg N ha^{-1} are associated with the more number of days taken for attaining a particular pheno-phase as nitrogen is known to increase vegetative growth of crop leading to increased crop duration.

Heat use efficiency (HUE)

A perusal of data in Table 2 indicated the highest heat use efficiency for seed as well as stalk under January 20 and the least under March 2 sown crop (Table 2). Sowing the crop at closer spacing led to marginally higher heat use efficiency for stalk but differences were very meager in case of seed. Application of each higher dose of N resulted in apparent increment in heat use efficiency for stalk up to the highest level but differences in HUE for seed between 60 and 75 kg N ha^{-1} were quite narrow. Although wider differences in HUE for seed was observed between other N doses. Heat use efficiency is directly proportional to dry matter accumulation by the plant. So, higher dry matter accumulation due to higher crop growth rate under January 20 sown crop improved its heat use efficiency. Likewise, improvement in heat use efficiency due to higher levels of N may also be due to enhanced growth rate of crop, hence heat use efficiency.

Correlation and regression studies

Simple correlation (r), regression (b) and coefficient of determination (r^2) among various parameters of sunflower (Tables 3) revealed highly significant ($P < 0.01$) negative correlation of AGDD at seed filling stage with seed yield indicating the influence of temperature on seed yield of sunflower. Data further indicate that with each unit increase in AGDD at seed filling stage, seed yield decreased by 5.919 units. AGDD at seed filling stage accounted for more than 53 per cent variation in seed yield of sunflower. Likewise, AGDD at maturity accounted for 60 per cent and seed filling duration accounted for 92 per cent variation in seed yield of sunflower and were significantly ($P < 0.01$) positively correlated with seed yield. The accumulation of growing degree days during seed filling (seed filling to maturity) was found to be highly significantly ($P < 0.01$) positively correlated with seed yield showing an increase of 3.96 units of seed yield due to each unit increase in accumulation of growing degree days during seed filling. Similarly, seed filling duration hadhighly significant ($P<0.01$) positive correlation and regression with seed yield, indicating that with each unit increase in seed filling duration, seed yield increased by 91.3 units.

CONCLUSIONS

Thermal energy utilization of the crop was improved by early sowing with ample nitrogen supply and optimum plant population. Thus, it can be concluded that agronomic measures such as adjustment of sowing time, intra row spacing and nitrogen supply etc. can be effectively used for harnessing the freely available solar energy.

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Effect of weather parameters on the initiation and progression of sheath blight of rice

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ABSTRACT

Sheath blight disease is one of the major fungal diseases of rice. Studies on the role of different weather parameters in the initiation and progression of the disease was carried out taking seven weather parameters as independent variables and cumulative and periodical increment in percent disease index as dependent variables. The main aim was to find out the most critical and contributory weather parameter (s) towards development of the disease in west central table land zone of Odisha. The study revealed that a heavy rainfall was conducive for initiation of the disease followed by low and intermittent rainfall of 13 to 38 mm, which was found favourable for progression of the disease. A maximum temperature range of 31^{0}C to 34^{0}C, minimum temperature range of 17^{0}C to 23^{0}C with 70 to 83 per cent evening relative humidity were found favourable for disease development and spread.

Key Words: Rice, sheath blight, weather parameters

Rice (*Oryza sativa* L) is the main food crop of majority of the Indian population. The crop is commonly infected by a number of fungal, bacterial and viral pathogens. Among the fungal diseases sheath blight caused by *Rhizoctonia solani* Kuhn has become one of the important diseases in all the major high yielding rice varieties grown in India. The disease causes enormous loss both in terms of quality and quantity and has a direct effect on yield reduction of rice. The disease is now known to occur in almost all the rice growing states of India causing up to 69% loss in yield (Sivalingham *et al.*, 2006) depending on cultivars, environmental conditions, crop stages at which the disease appears and cultivation practices. Different weather parameters play an important role in initiation and progression of the disease. In recent days, lot of emphasis is being given on weather based forecasting models for prediction of disease outbreak. Hashiba *et al.* (1982) observed that sheath blight disease development was most favourable at a temperature of 28^{0}C and 100% relative humidity with continuous low precipitation during the time of disease development. However the environmental conditions of different regions of the country differ a lot due to their geographical variations. Hence need was felt for thorough understanding on the weather parameters of west central table land zone of Odisha to study the weather relationship of the disease so as to predict, forecast and plan for effective protection measures. Considering the intensity of the disease, the present experiment was undertaken to find out the influence of weather parameters on the initiation and progression of sheath blight disease in west central table land zone of Odisha.

MATERIALS AND METHOD

A field experiment was conducted during two consecutive kharif season (2013 and 2014) at the research farm of All India Coordinated Rice Improvement Project, Regional Research and Technology Transfer Station, Chiplima (20^{0}21'N latitude and 80^{0}55'E longitude with an elevation of 178.8 m above mean sea level), Sambalpur, Odisha.

Sheath blight susceptible variety Swarna (MTU 7029) was sown in a plot size of 50 m^2 with a spacing of 15cm x 20 cm and replicated twice. The recommended dose of fertilizers @ 100: 50: 50 (N: P_2O_5: K_2O) kg ha^{-1} and FYM @ 10 t ha^{-1} were applied. N, P and K were supplied through urea, di-ammonium phosphate and murate of potash, respectively. All the recommended agronomic practices were followed for raising the crop.

Cumulative and periodical disease index

Natural development of the disease was permitted in the field. Three sampling units of 1m^2 was selected in each

Table 1: Development of sheath blight disease (cumulative and periodical increment in PDI) in relation to weather parameters (Pooled of 2013 and 2014)

Standardweek	Crop stage	Cumulative increase in PDI (%)	Periodical increment in PDI (%)	Temperature (^{0}C)		Relative humidity (%)		Total rainfall (mm)	Sunshine hours per day	Daily Wind speed (km h^{-1})
				Max.	Min.	Morning	Evening			
33	Vegetative	0	0	33.6	23.5	92.4	80.1	53.6	4.9	4.9
34	„	0	0	33.7	23.1	91.3	77.9	60.7	4.7	4.1
35	„	0	0	33.5	22.3	92.4	76.6	46.2	4.4	5.6
36	„	0	0	31.8	22.2	94.0	86.4	135.2	3.1	5.1
37	„	2.2	2.2	33.4	22.7	92.0	83.0	100.1	2.6	6.6
38	Reproductive	7.2	5.0	33.7	22.2	93.2	82.0	37.7	4.8	5.1
39	„	12.2	5.0	34.4	22.2	89.7	73.3	23.1	7.0	4.5
40	„	15.0	2.8	33.6	22.3	89.2	75.9	12.7	7.3	4.1
41	„	21.7	6.7	32.7	20.7	89.4	77.9	24.1	5.6	12.6
42	„	25.6	3.9	31.7	19.9	89.9	77.6	25.1	5.1	7.0
43	„	30.6	5.0	30.9	19.0	93.3	76.0	13.1	5.3	4.0
44	Maturity	32.2	1.7	30.7	16.7	91.6	69.8	3.0	7.6	3.0
45	„	32.2	0	30.8	14.5	90.7	67.2	0	9.1	2.0

plot and disease severity was recorded at weekly interval for ten randomly selected plants from each sampling units following SES scale (IRRI, 1996) starting from the initial infection of the disease till terminal disease severity. After scoring the percent disease severity of sheath blight disease, cumulative increase in percent disease index (CIPDI) was calculated following the standard formula

$$CIPDI = \frac{\text{Sum of all numerical ratings}}{\text{No.of observations X Maxmimum rating}} \text{ X } 100$$

The periodical increment in percent disease index (PIPDI) was also worked out from CIPDI and the weather parameters like maximum and minimum temperature, morning and evening relative humidity percentage, total rainfall in mm, sunshine hours per day and daily wind speed in km h^{-1} were also recorded from the meteorological station of RRTTS, Chiplima for the entire period of experimentation. Data were arranged according to standard meteorological weeks. Multiple regression analysis for prediction of disease severity was worked out to find out the most critical weather parameter(s) contributing much towards the disease severity by taking CIPDI and PIPDI as dependent variables and all the weather parameters as independent variables. All data were statistically analyzed using SPSS software version 21.

RESULTS AND DISCUSSION

Progress of the disease was measured in terms of CIPDI and PIPDI and designated as Y_1 and Y_2 respectively. Mean weather parameters like maximum temperature, minimum temperature, morning relative humidity, evening relative humidity, total rainfall, daily sunshine hours and daily wind speed of 2013 and 2014 were worked out at weekly interval and their pooled values were presented in Table 1.

The data revealed that, disease development and spread was observed from 37th to 45th Standard Meteorological Week (SMW) at average maximum temperature range between 31^{0}C -34^{0}C, morning relative humidity 93 per cent and a total rainfall of 534.5 mm which helped the pathogen infection and further progress of the disease. Bhukal *et al* (2015) reported that a maximum temperature between 31^{0}C to 33^{0}C, minimum temperature between 16^{0}C to 25^{0}C and more than 90 per cent relative humidity play major role in the progression of the disease. The disease initiation was at the later part of vegetative stage i.e., during 37th SMW. PDI values increased significantly and maximum PDI of 32.23 CIPDI was recorded at 44th SMW and disease progression ceased at 45th SMW.

Table 2: Correlation between weather parameters and increment in PDI (cumulative and periodical) in sheath blight disease of rice

Sl.No	Weather parameters	Cumulative increment in PDI	Periodical increment in PDI
1	Maximum temperature	-0.723**	0.124
2	Minimum temperature	-0.873**	0.002
3	Maximum relative humidity	-0.362	-0.347
4	Minimum relative humidity	-0.719**	0.007
5	Rainfall	-0.758**	-0.381
6	Sunshine hours	0.697**	0.076
7	Wind speed	-0.101	0.534

*Significant at 5% level, ** Significant at 1% level

Table 3: Multiple regression equation between environmental variables and increment in cumulative and periodical PDI of sheath blight disease of rice

Step	Multiple correlation between	Regression equation	R^2 Value
1	Y_1 and X_1,X_2,X_3,X_4,X_5	$333.695-4.467 X_1-2.129 X_2-2.220 X_3 +1.059X_4-0.205 X_5$	0.949**
2	Y_2 and X_1,X_2,X_4,X_5, X_7	$-51.204+0.856X_1-0.638 X_2+0.517 X_4-0.066 X_5+0.349 X_7$	0.669*

*Significant at 5% level, ** Significant at 1% level; X_1 =Maximum temperature, X_2 = Minimum temperature, X_3=Morning relative humidity, X_4= Evening relative humidity, X_5=Total rainfall, X_7= Wind speed/day, Y_1= Cumulative increment in PDI, Y_2= Periodical increment in PDI.

Correlation of sheath blight with weather parameters

Different weather parameters played important role in sheath blight development and spread. Correlation between the pooled data of weather variables and disease development presented in Table 2.

Maximum temperature had a significant negative correlation (r= -0.723**) with CIPDI which implies that increase in maximum temperature had a negative influence on progress of the disease and vice versa. During the period the maximum temperature gradually decreased from 34^{0}C to 31^{0}C with the progress of the disease and a maximum CIPDI of 32.23 per cent was recorded on 44th SMW with a maximum temperature of 31^{0}C (Table 1). On the contrary, a non significant positive correlation (r=0.124) was observed between maximum temperature and PIPDI.

A significant negative correlation (r= -0.873**) was observed between minimum temperature and CIPDI. During the period of disease progress i.e., from 37th to 44th SMW, the average minimum temperature gradually decreased from 23^{0}C to 17^{0}C and with the decline of minimum temperature, an increase in CIPDI was noticed. On the other hand, a non significant positive correlation (r= 0.002) was observed between minimum temperature and PIPDI. The highest increment of 6.67% in PIPDI was observed on 41st SMW with an average minimum temperature of 21^{0}C (Table 1).

The relationship of morning relative humidity with CIPDI (r= -0.362) and PIPDI (r= -0.347) was found negative and non significant. A range of 89 per cent to 93 per cent morning relative humidity was found suitable for disease development and spread (Table 1).

Evening relative humidity was found to have a significant negative correlation with CIPDI (r= -0.719**). During initiation of disease at 37th SMW (Table 1), the evening relative humidity was 83 per cent and it declined with advancement of disease. A non significant positive correlation was observed between evening relative humidity and PIPDI (r= 0.007). The maximum PIPDI of 6.67 per cent was recorded with an evening relative humidity of 78 per cent, where as a minimum PIPDI of 1.67 per cent was recorded after reduction of evening relative humidity to 69.8 per cent.

Rainfall was an important factor for sheath blight development. The disease initiated at 37th SMW recording 100 mm rainfall (Table 1) and was preceded by 135 mm total rainfall during 36th SMW which might have made the micro climate more suitable for disease initiation. Therefore, probably heavy rainfall was found favourable for disease initiation. A significant negative correlation (r=-0.758**) was observed between total rainfall and CIPDI while a non significant negative influence of rainfall was found on PIPDI (r= -0.381) which implies that the cumulative and periodical increment in disease was not increased with the proportion of rainfall. It seems that other weather parameters were also simultaneously responsible for disease progress. A range of 13 to 38 mm of intermittent total rainfall was found favourable for disease spread.

The effect of sunshine hours on CIPDI was significantly positive (r= 0.697**) which means that with increase in daily sunshine hours, the disease also increased due to the production of favourable micro climate within the crop canopy. A non significant positive correlation (r=0.076) was observed between sunshine hours day $^{-1}$ and PIPDI. A range of 2.58 to 7.32 sunshine hour day $^{-1}$ was found suitable for development and spread of sheath blight (Table 1).

Wind speed had non significant negative and positive influence on CIPDI (r=-0.101) and PIPDI (r= 0.534) respectively. The highest periodical increment in PDI (6.67 per cent) was observed when average wind speed was maximum (12.63 km hr^{-1}) during 41st SMW (Table 1). Heavy cyclonic air was blowing at that period coincidentally during both the years of experiment which might facilitated the spread of sclerotia of the fungus and aggravated the disease.

Multiple correlation coefficients

To develop a quantitative relationship between different weather variables and development of sheath blight (CIPDI and PIPDI), coefficient of determination (R^2) was worked out through multiple regression analysis.

Multiple correlation coefficients indicated strong relationship between disease and different weather variables. Multiple regression analysis was performed to handle seven independent weather variables and to identify critical and much contributing weather variable (s) separately towards the dependent variables i.e., CIPDI and PIPDI of sheath blight.

Combined effect of weather variables was found significantly favourable for sheath blight development and spread as indicated by the significant coefficient values of multiple determination. The results of multiple regression analysis for prediction of sheath blight severity was accounted for the linear function involving a negative correlation with all the weather variables except evening relative humidity in case of CIPDI (Table 3). Whereas considering the PIPDI (Table 3), the result of multiple regression analysis revealed a positive correlation with maximum temperature, evening relative humidity and wind speed and negative correlation with other weather factors. The combined effect of these weather parameters had contributed much towards the PDI increment. Highly significant R^2 value (0.949**) was obtained for CIPDI which implies that the weather variables were responsible for up to 94.9 per cent variation in cumulative increase in PDI. Similarly, in case of PIPDI weather variables were responsible for up to 66.9 per cent variation. Out of seven weather parameters, maximum and minimum temperature, evening relative humidity and rainfall were identified as critical parameters through multiple regression analysis and had their positive or negative contributions towards the PDI increment. Maximum and minimum temperature and rainfall had negative correlation with CIPDI. Whereas evening relative humidity had positive correlation with both CIPDI and PIPDI which means that increment of evening relative humidity predicts higher disease severity.

The result of multiple regression analysis indicated that a heavy total rainfall of 135mm and 100mm during 36th and 37th SMW respectively paved the way towards initiation of the disease and a range of 13mm to 38 mm low and intermittent rainfall during the later weeks aggravated the disease. An average minimum temperature of 21^{0}C was found critical for PIPDI. A maximum temperature range of 31 to 34^{0}C and minimum temperature range of 17 to 23^{0}C favoured the disease. Evening relative humidity had a positive contribution towards PDI. PIPDI recorded its minimum value (1.67 per cent) after a sudden fall of evening relative humidity from 76 per cent to 69.8 per cent at 44th SMW and after that with further decrease in evening relative humidity, the increment of the disease ceased at 45th SMW. An average range of 70-83 per cent evening relative humidity was found favourable for disease development and spread. The result is in conformity with Dutta and Kalha (2011) who reported that high and frequent rains with moderate temperature (up to 30^{0}C) coupled with high relative humidity favoured the spread of disease. Biswas *et al* (2012) also identified different agro meteorological parameters responsible for enhancing sheath blight severity in the field and reported that maximum air temperature between 33-34^{0}C and minimum air temperature of 24-26^{0}C coupled with more than 90 per cent relative humidity aggravated the disease development. They also found a strong positive relationship between cumulative rainfall over the season and disease development. Thind *et al* (2008) and Tiwari and Chaure (1997) reported maximum disease development at a temperature range of 25^{0}C to 30^{0}C and relative humidity of more than 80 per cent. Individual contribution of each environmental factor towards CIPDI and PIPDI played important role on sheath blight development but their combined effect was more likely to help in the process of disease development.

CONCLUSION

So, it can be concluded that heavy rainfall was conducive for initiation of sheath blight disease. Further, a maximum temperature range of 31^0C to 34^0C and minimum temperature range of 17^0C to 23^0C coupled with 70% to 83% evening relative humidity were proved to be the critical parameters for disease development.

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Assessment of thermal heat requirement, radiation energy, water use efficiency, and yield of mango cv Dashehari using fertigation method

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ABSTRACT

Thermal heat requirement as well as energy components depend on weather parameters. Critical phenological stages was taken into consideration for the thermal heat requirement during 2013-15 under fertigation treatment (25, 50 and 75 per cent of recommended fertilizer dose) in mango cv Dashehari at Lucknow region. Mango productivity varied from 4.54-11.84 t ha^{-1} across different fertigation regimes as a result of differential thermal heat accumulation. In the treatment 25 per cent RDF, productivity of 5.23, 11.13 and 6.12 t ha^{-1} was recorded during 2013, 2014 and 2015 while in 50 per cent RDF, 6.23, 11.84 and 7.76 t ha^{-1} was observed. The maximum yield reduction (37.5, 14 and 26.1%) was found in control plot. A significant variation in radiation energy received during the field experiment was revealed and a range of 8.97 to 16.27 mm day^{-1} extraterrestrial radiation was observed at different critical phenological stages. The heat use efficiency (HUE) varied between 2.54-6.78 g $m^{-2}{}^{\circ}Cd^{-1}$ across seasons and treatments. Water use efficiency (WUE) of 10.8, 14.1, 13.5 and 11.7 kg fruits m^{-3} was recorded in different fertigated treatments. The highest reduction in WUE was noted in control (23.9%) followed by 17.2 and 4.8% in 25 and 50 per cent as compared to 75 per cent fertigation regimes.

Keywords: Agroclimatic indices, radiation dynamics, water use efficiency, productivity, mango,

Mango (*Mangifera indica*) is economically one of the most important fruit crop in India and UP being the important states in the country for earning good economic returns through mango export. The information on abiotic stresses like temperature, moisture, radiation, evaporation, during fruit developmental stages are the key factors for orchard sustainability and securing farmer's livelihood. The crop is immensely influenced by climatic factors during fruiting season (Rajan, 2012). Differential moisture regimes particularly fertigation plays a pivotal role in improving the productivity of mango and thus responsible for variations in energy use in terms of water use efficiency. Generally, higher evaporation from the soil surface and absence of rainfall, with high wind velocity and temperature makes a drier environment, the obvious results being fruit drop, forced maturity, resulting into low quality fruit production (Ravishankar *et al.,* 2011; Adak *et al*., 2013). Additionally, extended cold periods, severe cold (-0.2^{0}C to -1.2^{0}C during 2013) also impacted fruit production. Quantification of thermal heat requirements of fruit crop like mango is essentially important to worked out to mitigate abiotic stresses. Daily maximum and minimum temperatures undergoes great variation and seasonal dynamism also influences fruits production, application of heat unit accumulation is a better option for relating changes in energy use efficiency (Perry *et al*., 1993; Singh *et al.,* 2000; Umber *et al*., 2011). Since the information on all these aspects particularly its energy use across seasons and hydrothermal regimes in mango production under subtropical climatic condition is lacking, hence, a detailed study is therefore set out to quantify the energy requirements and its use efficiency using fertigation scheduling method.

MATERIALS AND METHODS

A field experiment on different fertigation scheduling was carried out on a 30 years old mango cv Dashehari (10×10 m spacing) in the experimental farm of Central Institute for Subtropical Horticulture (26.54^{0}N Latitude, 80.45^{0}E Longitude and 127 m above mean sea level), Rehmankhera, Lucknow, Uttar Pradesh during 2013, 2014 and 2015 to generate the information on energy use efficiency across fruiting seasons. The area falls under subtropical region and soils were characterized under the category of Indo-Gangetic alluvium. Four treatments were placed in a randomized complete bock design using five replications (Table 1). The irrigation was given through drippers having capacity of 8 l h^{-1} on every alternate days and the quantity was decided on the basis of open pan

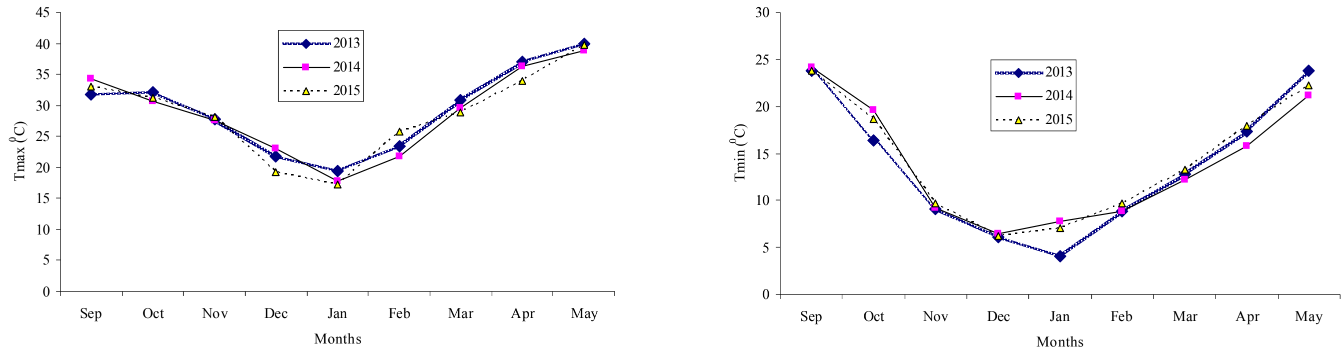

Fig. 1: Monthly average temperatures during mango growing season

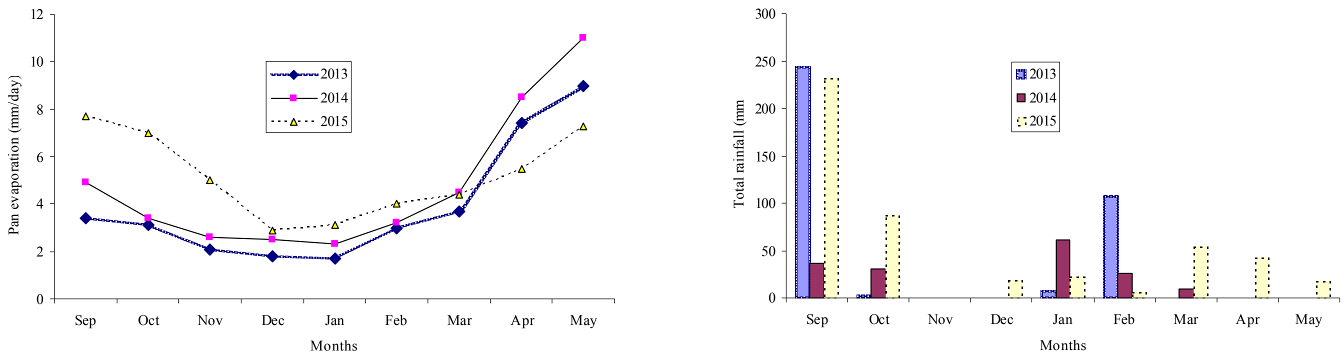

Fig. 2: Monthly average pan evaporation and total rainfall during mango growing season

evaporation data. Fruit productivity was recorded at full maturity stage by quality parameters like Total Soluble solid, acidity and ascorbic acid. The heat unit indices *viz*., growing degree days (GDD), heliothermal unit (HTU), and photothermal units (PTU) were calculated to quantify the thermal heat requirements. All these indices were calculated as follows:

Growing degree days (GDD) = $\Sigma(T_{Max} + T_{Min})/2 - T_{Base}$

Heliothermal units (HTU) = GDD × actual bright sunshine hour (n)

Photothermal units (PTU) = GDD × day length (N)

where T_{Max} and T_{Min} are the maximum and minimum temperatures (°C) of the day and T_{Base} is base temperature which was taken as 15°C (Whiley *et al.,* 1991). N indicates maximum possible bright sunshine hours or day length and calculated as

$N = (24/\pi) \times Ws$

Ws is the sunset hour angle (Radian) = Arc Cosine [-tan (Φ) × tan (σ)]

Φ = Latitude in radian,

σ = Solar declination in radiation, calculated as follows

$\sigma = 0.409 \times \text{Sine}\,[(2 \times \pi \times J)/d - 1.39]$

Where J= Julian days (1 to 365/366) and d = No. of days in the year

The extraterrestrial radiation (Ra) and incoming short wave radiation (Rs) were estimated using Allen *et al*., (1998). After harvesting in June-July, during the month of September, post harvest vegetative phases started. The events for phenological stages described as flower bud differentiation (December to January), flowering (Feb to March) and fruit set, development to maturity (April to May-June). The energy use efficiency in terms of heat or water energy was also derived. Heat use efficiency was estimated as productivity (g m^{-2}) per unit of agroclimatic indices and water use efficiency was calculated as productivity per (kg) m^3 of water applied. These indices were calculated on daily basis taking 1st September as base for each year since mango is harvested during June-July in northern India. The calculation was considered up to physiological maturity (end of May in each year). The data was statistically analyzed and significance was concluded at 5% level of significance using SPSS version 16.0.

RESULTS AND DISCUSSION

Meteorological condition during the mango growth cycle

The mean monthly meteorological parameters observed during mango growth and developmental is

Table 1: Details of different ferigation scheduling applied in mango cv Dashehari

	T_1	T_2			T_3			T_4		
Stages		N	P	K	N	P	K	N	P	K
After harvest	100% NPK in basin	25	50	15	20	30	10	10	15	5
during flowering	-	20	25	15	20	20	10	10	10	5
marble size stage	-	30	-	45	10	-	30	5	-	15
		75%	75%	75%	50%	50%	50%	25%	25%	25%

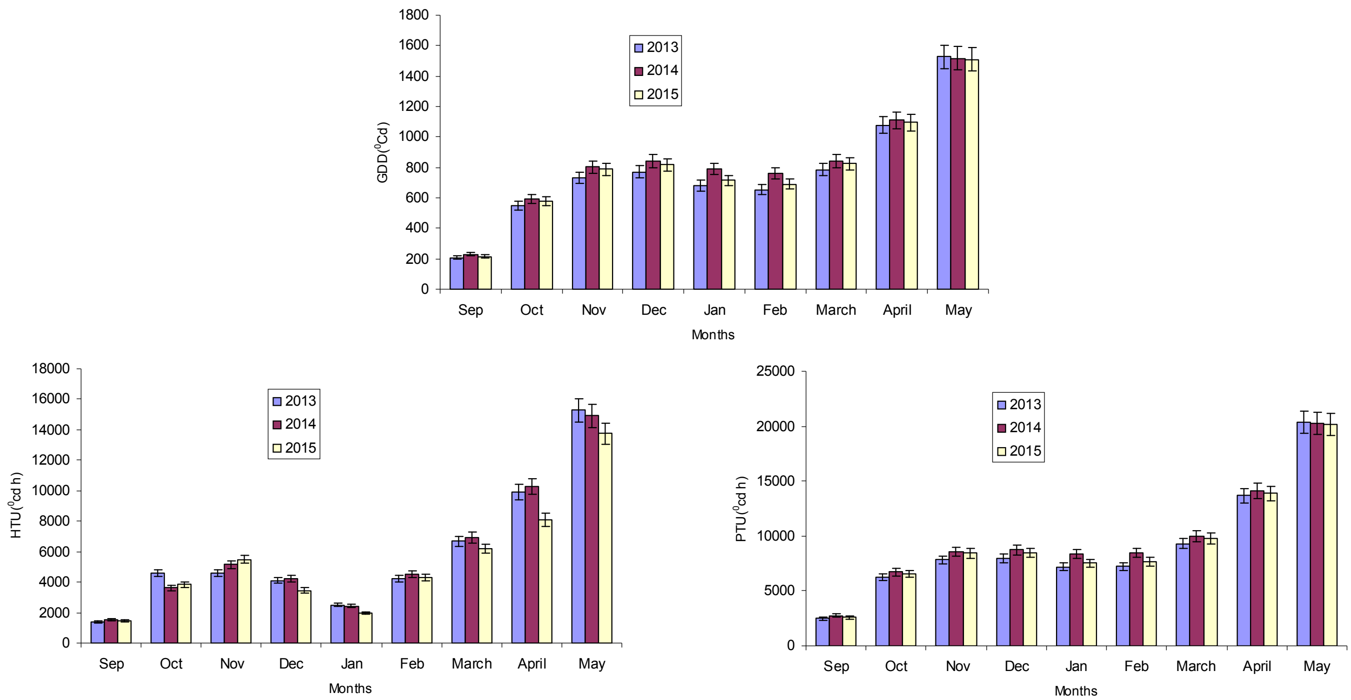

Fig. 3: Quantification of thermal heat requirements at different critical phenological stages in Dashehari mango (month wise)

presented in the Fig. 1-2. The monthly average maximum and minimum temperatures (T_{max} and T_{min}) varied between 19.4-39.9 and 4.1-24.1°C respectively across three seasons. The pan evaporation ranged from 1.8 to 11.0 mm day^{-1}. A range of 3.7-8.5 mm day^{-1} pan evaporation was recorded during the initial fruit growth stages across three seasons. Temporal variation in total amount of rainfall received was depicted. During the month of September a total of 243.2, 36.8 and 231.4 mm of rainfall were received. Unseasonal rainfall of 19.4 mm during December 2015 was received. Similarly, unseasonal rainfall was also received during the months of January and February. During 2015 fruiting season, a total of 54.2, 41.8 and 18.0 mm of rainfall were received during fruit developmental stages (pea and marble stages).

Thermal heat requirement at different phenological stages

Different thermal heat accumulation was revealed with the higher in 2014 than both the years (Fig. 3). During flowering period, 651.8 to 762.4 °Cd while, at fruit growth, 785.0 to 843.0 °Cd heat accumulation was estimated across seasons. The accumulated GDD ranged between 1078.1 and 1527.4, 1110.5 and 1516.9 and 1094.0 and 1509.0°Cd during marble size stage to fruit maturity stages in 2013, 2014 and 2015 respectively. The thermal heat accumulation at different critical crop phenological stages in general indicates the stage-wise heat requirement and also essential for harvesting the economic parts of the crop (Nagarajan *et al.*, 1994; Villordon *et al.,* 2009; Mu˜noz *et al*., 2012). Suresh *et al*. (2013) observed that a range of 1567-2780 cumulative GDD from anthesis to maturity in oil palm hybrids under Pedavegi, Andhra Pradesh condition.

Energy use efficiency and crop productivity

A range of 10.2-11.8, 5.9-8.04 and 4.5-7.3 t ha^{-1} productivity across different fertigation regimes were noted

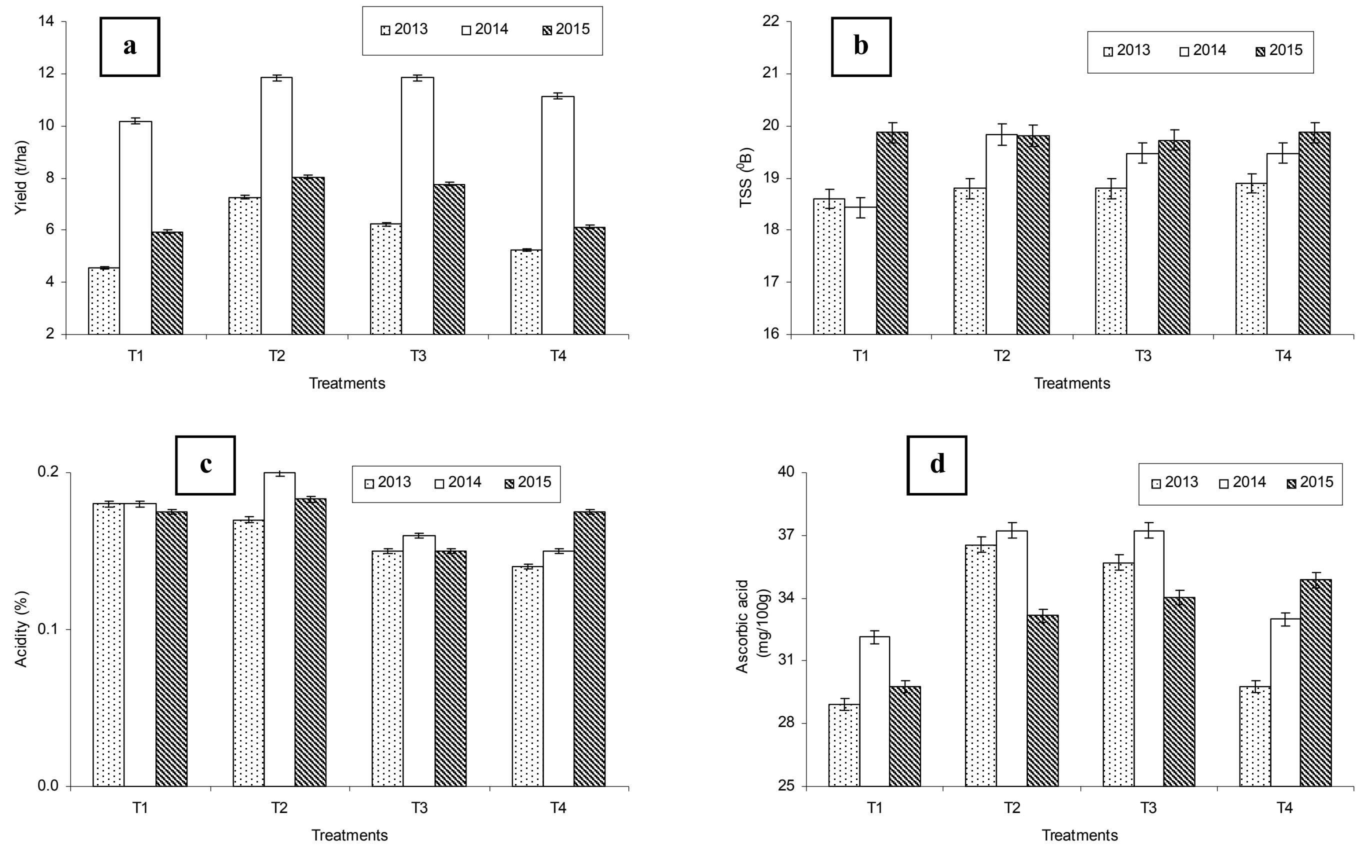

Fig. 4: Changes in productivity and quality parameters under different fertigation regimes in mango cv Dashehari

(Fig. 4a). Mango productivity was higher in 2014 followed by 2015 and lowest in 2013years. A 25 per cent recommended dose of fertilizer (T4) exhibited a productivity of 5.2, 11.1 and 6.1 t ha^{-1} in 2013, 2014 and 2015 season while 50% RDF (T3), 6.23, 11.84 and 7.76 t ha^{-1} was observed (Fig. 4). The maximum yield reduction (37.5, 14 and 26.1%) was found in control plot during experimental periods. Yield reduction in T_4 as compared to T_2, was estimated as 28.0, 6.0 and 23.9 per cent in 2013, 2014 and 2015 respectively while in case of T_3, 14.2 per cent in 2013 and 3.5 per cent in 2015 was observed. Fruit quality parameters like TSS and acidity did not vary significantly across different fertigation treatments. In case of ascorbic acid content, a significant change was observed and a range of 28.91-36.56, 32.54-37.22 and 29.76-34.86 mg/100g was estimated in 2013, 2014 and 2015 (Fig. Fig. 4 b,c,d).Optimum soil moisture is required for obtaining sustainable yield in mango as soil moisture content at fruit set to developmental periods is key factors for determining the quantity as well as quality production. Higher yield and quality in T_2 treatment may be because of higher nutrients applied at critical phenological stages with higher percentage of K during marble stage. Lower yield in other treatments may be because of low fertigation regime.

Such kind findings in productivity variations under different fertigation regimes across different agroecological regions were also observed (Panwar *et al.*, 2007; Bhriguvanshi *et al.*, 2012; Adak *et al.*,2014),

The efficiency with which the mango fruit was produced was studied in terms of its energy use and presented in Fig. 5. The heat use efficiency (HUE) varied between 2.54 and 4.06, 5.83 and 6.78 and 3.38 and 4.57 g m^{-2} °Cd^{-1} in 2013, 2014 and 2015 respectively (Fig. 5a). The highest HUE was recorded in T2. Moreover, the reduction in HUE was also quantified and it was observed that maximum reduction in energy use efficiency was 37.5 per cent in control plot (T_1), followed by 28 and 14.2 per cent in T_4 and T_3 treatments during 2013. . Considering HTU, it was inferred that the HUE exhibited 0.30-0.47, 0.68-0.79 and 0.43-0.58 g m^{-2} °Cd h^{-1} in 2013, 2014 and 2015 years across different fertigation treatments (Fig. 5b). The heat use efficiency using PTU as an index showed higher value of 0.50-0.59 g m^{-2} °Cd h^{-1} during 2014 as compared to 2013 (0.22-0.36 g m^{-2} °Cd h^{-1}) and 2015 (0.30-0.40 g m^{-2} °Cd h^{-1}) years (Fig. 5c). Higher HUE in 2014 indicated higher thermal heat accumulation and better utilization of energy.

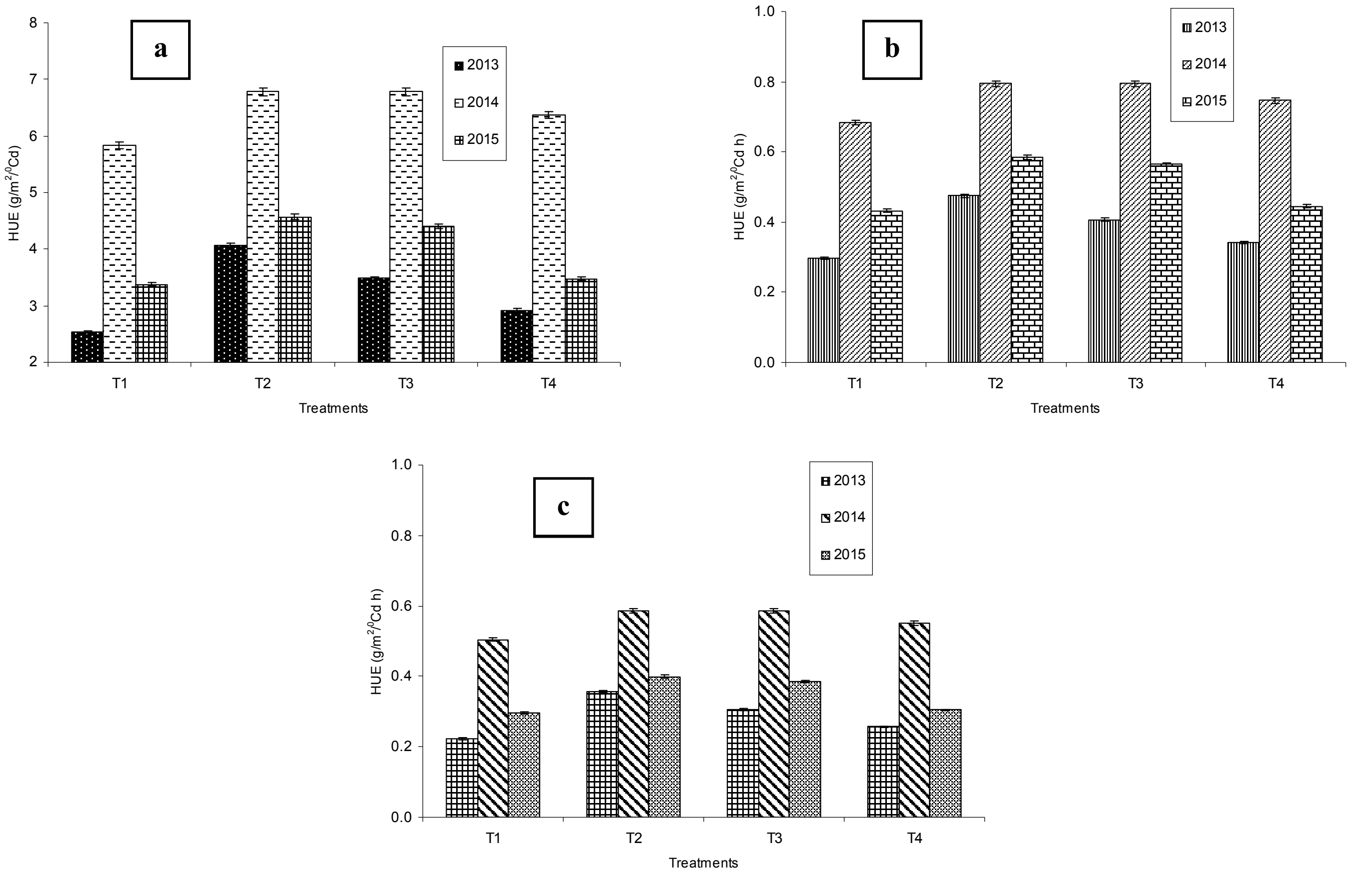

Fig. 5: Significant changes in heat use efficiency in mango cv Dashehari using different thermal indices (GDD-a, HTU-b , PTU-c)

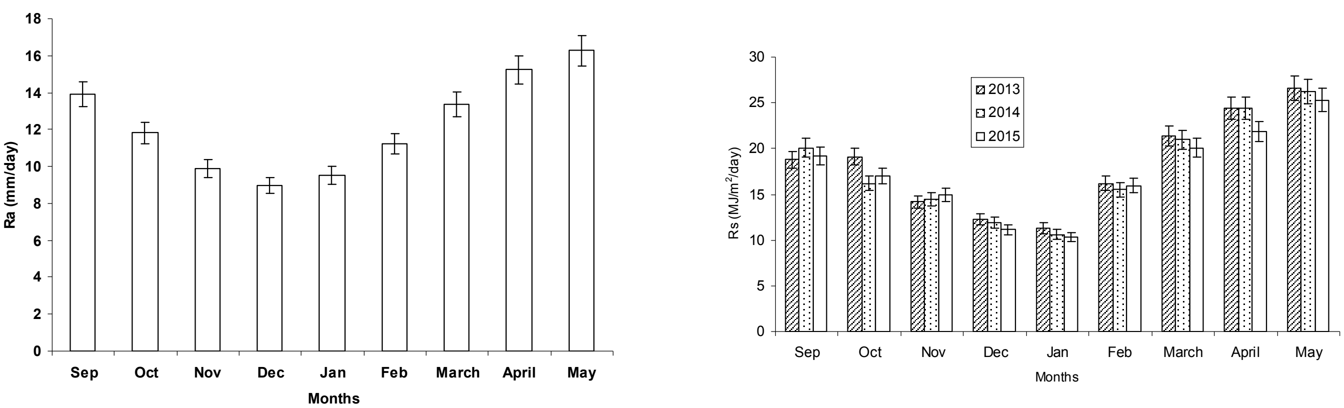

Fig. 6: Variations in extraterrestrial radiation and Incoming short wave radiation during mango growing season

Changes in radiation energy and water use efficiency

A significant change in terms of radiation energy received during the field experiments was revealed (Fig. 6). Extraterrestrial radiation (Ra) received during the critical phenological stages ranged from 8.97 to 16.27 mm day^{-1}. Radiation energy was estimated to be 8.97-9.53, 11.23, 13.28, 15.23 and 16.27 mm day^{-1} during FBD (Flower bud differentiation), flowering, pea stage of fruit, marble size stage and finally at physiological maturity. A critical analysis of Rs (incoming shortwave solar radiation as a function of PAR) indicated wide variations across different phenological stages of the mango fruit. It was also found that highest Rs was received in 2013 fruiting season while 2014 and 2015 fruiting season received comparatively lower value (Fig. 6). This information is very crucial to have an idea about how the fruit crop responses under low radiation conditions. Highest and lowest value was estimated as 6.97 and 28.43 MJ m^{-2} day^{-1}. The Rs assessed at different critical crop phenological stages (month wise) during three consecutive mango fruiting seasons revealed that during the initial

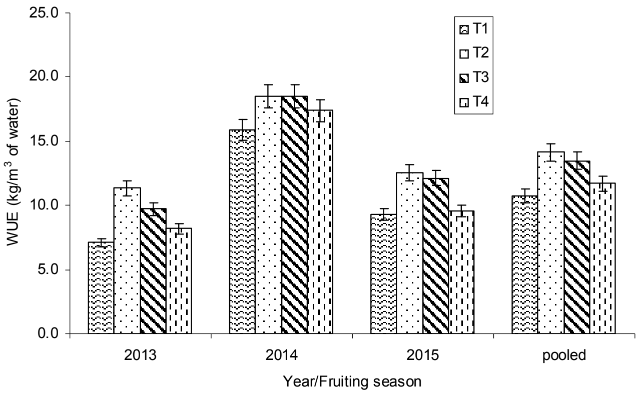

Fig. 7: Dynamics of water use efficiency in mango cv Dashehari under different fertigation system

month a value of 18.8-20.08 MJ m^{-2} day^{-1}in the month of September was recorded across the seasons. The lowest value was observed to be 10.04-12.22 with a mean value of 10.75 MJ m^{-2} day^{-1} during winter months from December-January. The maximum possible sunshine hours during the critical mango growth period was calculated and it was found in the range of 10.34 to 13.55 hours with a standard deviation of 0.98 and coefficient of variation of 8.5 per cent. It decreased from September to December and after that started increasing with the advancement of summer seasons (clear sky). Differential solar and micro environmental regimes are reported to affect on productivity of different crops (Adak *et al*., 2012 and 2013). Highest water use efficiency (WUE) was noted in T_2 across three consecutive seasons. In other fertigation treatments (T_3 and T_4), WUE of 8.2-9.7, 17.4-18.5 and 9.6-12.1 kg fruits m^{-3} was recorded during 2013, 2014 and 2015 respectively (Fig. 7). A pooled value of 10.8, 14.1, 13.5 and 11.7 kg fruits m^{-3} was inferred in T_1 to T_4 respectively. The WUE decreased in other fertigation treatments as compared to T_2. Maximum reduction observed in T_1 (23.9%) followed by T_4 (17.2%) and T_3 (4.8%) treatments. Variations in WUE under different hydro thermal regimes across different agroecological regions were also observed by Spreer *et al*., (2007) and Bhriguvanshi *et al*., (2012). Such variations may be due to irrigation regimes applied coupled with weather parameters dynamics particularly pan evaporation, radiation and evapotranspiration (Adak *et al*., 2014; Mehta and Pandey, 2015).

CONCLUSION

Wide variations in thermal heat requirement in mango cv Dashehari at different critical phenological stages during 2013, 2014 and 2015 fruiting season was inferred.. Higher heat accumulation was observed in 2014 mango growing season. The highest productivity was recorded in 2014 followed by 2015 and lowest in 2013. A range of 10.18-11.84, 5.94-8.04 and 4.54-7.26 t ha^{-1} productivity across different fertigation regimes was noted in the respective years. Higher heat and water use efficiency were recorded in the treatment where 75 per cent of recommended fertilizer doses were applied at critical phenological stages. A range of 2.54 to 6.78 g m^{-2} °Cd^{-1} HUE and 8.2 to 18.5 kg fruits m^{-3} was estimated across three seasons with higher value in 2014 seasons. Lower heat and water use efficiency was recorded in the treatments wherever 25 and 50% of recommended fertilizer doses were applied.

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Trends in temperature and rainfall extremes during recent years at different stations of Himachal Pradesh

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ABSTRACT

Daily maximum and minimum temperatures of 4 stations and rainfall of 22 stations of Himachal Pradesh for the period of 1970 to 2014 have been used to work out extreme climate indices and trends. The temperature and rainfall indices for different stations studied showed no uniform trend. The results indicated the increasing trend in minimum of maximum and minimum of minimum temperature. The increased frequency of warm nights and warm spell but decrease in the number of hot days and hot nights were observed at Bajaura and Shimla. The maximum one day rainfall amount, maximum 5-day rainfall during the month and very wet days were found to decrease at most of the stations in the state. Consecutive wet days (CWD) and annual total rainy days (PRCPTOT) showed statistically mixed trends at various stations in the state.

Key words: Extremes, climate indices, precipitation, temperature, rainfall, trend

The term 'Global warming' and 'Climate change' are often used interchangeably, but there is a difference between these two. Global warming is the gradual increase of the earth's average surface temperature due to green-house gases in the atmosphere, whereas the 'Climate change' is a broader term. It refers to long-term changes in climate; including changes in average temperature and rainfall pattern due to climate change. The globally averaged surface temperature data shows a linear warming trend of 0.85 °C (0.65 to 1.06 °C) during the period 1880–2012 (IPCC, 2014). The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 °C (0.72 to 0.85 °C), based on the single longest dataset available (IPCC, 2013). In the context of global warming, the study of extreme weather events has become important due to its impact on socio-economic activities (Karl and Easterling, 1999). Various extreme weather events over the India in the past 100 years have been reviewed and their causes and socio-economic impacts are discussed (De *et al*., 2005). A widespread warming over Indian region through both frequency and intensity indices of temperature extremes has been noticed by Revadekar *et al*. (2012). The significant increasing trends have been observed in fifteen states of India including Himachal Pradesh with the highest (+0.06 ^{o}C/year) increase in winter mean maximum temperature in Himachal Pradesh followed by Goa, Manipur, Mizoram and Tamil Nadu (+0.04 to 0.05 ^{o}C/year) (Rathore *et al*., 2013). A study on the trends in extreme rainfall indices for the period 1901 to 2000 over India showed significant positive trend for most of these indices over the west coast and north-western parts of Indian peninsula (Joshi *et al*., 2006). Increasing frequencies of heat stress, drought and flooding events are also projected for the rest of the century and these are expected to have greater impacts on sectors with closer links to climate, such as water, agriculture and food security (IPCC, 2012). Therefore, keeping in the view, the impact of increasing changes in climate, an attempt has been made in present study to study the trends in temperature and rainfall extremes in Himachal Pradesh (at station level) over past few decades.

MATERIALS AND METHODS

The observed daily data of maximum and minimum temperature of 4 stations and rainfall of 22 stations in Himachal Pradesh during the period 1970 to 2014 has been used to calculate various extreme climate indices. The time period for which data of various stations is used given in Table 1. The RClimDex, a program script written in R language developed at the Meteorological Service of Canada was used for weather data quality assessment and also for working out the indices and their trends (Zhang and Yang, 2004). Station records with more than 25% of the data either missing or recording zero for any particular index was not considered for analysis. The significance of each trend was examined at 95% confidence level.

Table 1: List of stations selected for the study

Stations	Latitude (^{0}N)	Longitude (^{0}E)	Altitude (m)	Data base
Mandi	31.70	76.93	771	1970-2014
Hamirpur	31.70	76.50	782	1971-2014
Kumarsain	31.13	77.44	1693	1971-2014
Dharamshala	32.22	76.31	1246	1972-2013
Kandaghat	30.97	77.10	1484	1972-2014
Keylong	32.57	77.03	3098	1972-2014
Pachhad	30.56	77.30	1567	1972-2014
Rohru	31.20	77.75	1553	1972-2014
Dehra	31.87	76.32	767	1973-2013
Arki	31.15	76.97	1090	1973-2014
Nahan	30.55	77.28	677	1973-2014
Jubbal	31.10	77.70	1927	1974-2014
Karsog	31.38	77.20	1465	1974-2014
Palampur	32.10	76.54	1253	1974-2014
Theog	31.12	77.33	2033	1974-2014
Una	31.48	76.28	389	1974-2014
Kasauli	30.90	76.96	1783	1975-2014
Mashobra	31.13	77.22	2107	1981-2014
Ghumarwin	31.43	76.71	829	1982-2013
Shimla	31.09	77.17	2208	1985-2014
Bajaura	31.84	77.16	1074	1986-2014
Dhaulakuan	30.56	77.30	411	1987-2014
Banjar	31.63	77.34	1419	1988-2014

Table 2: Trends in temperature extreme indices

Index (Station)	Bajaura	Dhaulakuan	Palampur	Shimla
Hot days (SU25)	NS	0.596	0.66	NS
Tropical nights (TR20)	0. 33	0.036	-0.169	-0.089
Hot nights (TR25)	NS	-0.365	-0.021	NS
Warm nights (TN90p)	0.005	NS	NS	-0.203
Warm spell duration (WSDI)	0.197	NS	NS	0.697
Maximum of maximum temperature (TXx)	-0.014	-0.038	0.035	0.051
Minimum of maximum temperature (TXn)	0.018	-0.075	0.019	0.084
Maximum of minimum temperature (TNx)	-0.004	-0.071	-0.021	-0.035
Minimum of minimum temperature (TNn)	0.003	0.004	0.020	-0.058

RESULTS AND DISCUSSION

Trends in temperature extreme indices

The trends in temperature indices for different stations were ascertained following the test of statistical significance for each temperature index. The slope values of the all significant temperature extremes are given in the Table 2. The values of temperature indices showed mixed trends. The

Table 3: Trends in extreme rainfall events

Station	Highest one day rainfall (Rx1day)	Maximum 5-day Precipitation (Rx5day)	Simple daily intensity index (SDII)	Number of heavy precipitation days(R10)	Number of very heavy precipitation days(R20)	Consecutive dry days CDD	Consecutive wet days CWD	Very wet days R95p	Extremely wet days R99p	Annual total rainy days (PRCPTOT)
Arki	-0.165	-1.384	NS	-0.337	-0.238	0.185	-0.024	-2.34	-0.605	NS
Bajaura	-0.409	-0.843	-0.073	-0.23	-0.157	0.052	-0.009	-3.66	-0.902	-5.96
Banjar	-0.917	NS	-0.07	0.059	-0.125	0.269	-0.05	-1.741	-3.568	1.211
Dehra	-0.478	-0.564	-0.209	0.268	0.006	-0.746	0.036	-1.894	-1.182	4.026
Dharamshala	0.228	0.264	0.07	NS	0.193	-0.219	-0.104	3.352	0.043	11.217
Ghumarwin	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139	-0.139
Hamirpur	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	NS	-0.065	-0.065	-0.065
Jubbal	-0.336	-0.095	-0.024	-0.238	-0.081	0.351	0.025	0.542	0.574	-4.185
Kandaghat	-0.484	-1.095	-0.026	-0.214	-0.165	0.482	-0.055	-1.996	-1.32	-6.439
Karsog	0.171	-0.318	0.012	-0.103	-0.051	0.069	-0.037	2.058	1.3	-1.059
Kasauli	-1.064	-2.238	-0.236	-0.221	NS	-0.039	-0.083	-10.522	-3.119	-16.307
Keylong	-0.109	-0.042	-0.031	0.014	0.017	NS	0.011	-0.353	-1.041	0.968
Kumarsain	NS	NS	NS	0.345	0.204	0.077	0.001	NS	2.065	8.668
Mandi	-0.703	-1.517	-0.193	-0.114	-0.214	NS	-0.041	-5.14	-2.879	-6.593
Mashobra	-0.187	-0.88	-0.088	-0.272	-0.123	0.095	0.044	-4.977	-1.251	-6.735
Nahan	0.137	-0.744	-0.153	-0.037	-0.121	-0.232	-0.03	-0.609	0.524	-2.935
Pachhad	-1.295	-2.213	-0.063	NS	-0.233	0.323	-0.033	-6.451	-2.727	NS
Rohru	0.261	0.551	0.015	0.128	0.088	-0.653	0.07	3.703	0.682	6.076
Sarkaghat	1.86	3.089	0.095	0.144	0.211	0.36	0.091	6.194	4.003	11.658
Shimla	1.416	1.758	NS	0.521	NS	0.044	0.031	NS	3.282	NS
Theog	-0.749	-0.585	-0.065	-0.19	-0.103	0.146	-0.075	-2.228	-0.969	-5.301
Una	0.45	0.702	0.018	0.118	-0.016	-0.179	0.007	0.476	-0.309	1.927

trend for hot days (SU25) was observed to be significantly increasing at Dhaulakuan and Palampur whereas hot nights (TR25) were decreasing at these stations. Warm nights (TN90p) showed increasing trend at Bajaura and decreasing at Shimla whereas warm spell duration (WSDI) showed increasing trend at both of these stations. The trend of nights with minimum temperature below 20°C (TR20) was observed to be decreasing at Palampur and Shimla whereas it was increasing at Bajaura and Dhaulakuan.

The index of monthly maximum value of maximum of maximum temperature (TXx) indicated increasing trend at Palampur and Shimla whereas decreasing at Bajaura and Dhaulakuan. Events of minimum of maximum temperature (TXn) showed significantly increasing trend at Bajaura, Shimla and Palampur stations whereas decreasing at Dhaulakuan. Events of maximum of minimum temperature (TNx) are showing decreasing trend at all the stations whereas minimum of minimum temperature (TNn) is increasing at all the stations except Shimla. Though annual count of hot days (SU25) and hot nights (TR25) are observed to be non significant at Bajaura but the tendency of the intensity for minimum of maximum and minimum of minimum temperature has shifted for more number of days which might had consequence for not allowing sufficient chilling hours for apple flowering in the Kullu region.

The observations for the extreme temperature indices during past 45 years showed mixed trends. In a similar study conducted by Lunagaria *et al*. (2015) in Gujarat, also found mixed trends for temperature indices at majority of the stations. Generally increasing trend in mean maximum temperature during winter, summer, post monsoon, annually and during each month has been reported for Himachal Pradesh over the last six decades (Rathore *et al.*, 2013). The time period considered for analysis and methodology adopted in present study might be the one of the reasons for non conformity of results with them.

Trend in extreme rainfall events

The trends for rainfall indices were observed to be mostly significant but they were mixed, both increasing and decreasing. The index of maximum one day rainfall amount (RX1day) was observed to be decreasing significantly at 14, increasing at 7 and non significant at one station out of 22 stations studied (Table 3). In case of maximum five day rainfall (RX5day) also, trends were significantly decreasing at 14 and increasing at 6 stations. Very wet days (R95) and extremely wet days (R99) also showed deceasing trends at 13 and 14 stations, respectively. In case of heavy precipitation days (R10), very heavy precipitation days (R20) and consecutive wet days (CWD), trends were again observed to be decreasing at 12, 13, and 11 stations, respectively. Consecutive dry days (CDD) and annual total rainy days (PRCPTOT) showed statistically mixed trends. This observation is contrary to the existing belief that extreme heavy precipitation are on rise in Himachal Pradesh as the most of the indices are observed to be decreasing at more number of stations. Rathore *et al*. (2013) has also reported reduction in rainfall in the order of 2.85 mm/year during southwest monsoon (June to September), 0.21 mm/year during post monsoon (October to December) and 3.26 mm/year annually (January to March) in the state. Mixed trends for RX1, RX5day and R100 indices have been observed by Lunagaria *et al*. (2015) in Gujarat.

CONCLUSION

Mixed trend pattern was observed in the state for most of the temperature and rainfall extreme indices. The trend in hot days was observed to be significantly increasing at Dhaulakuan and Palampur whereas hot nights were decreasing at these stations. The rainfall indices had also no uniform pattern for negative or positive trend throughout the state. The index of maximum one day rainfall amount (RX1day), monthly maximum 5-day rainfall (RX5day) and very wet days (R95p) were observed to be decreasing at more numbers of the stations. The rainfall is the parameter having very high variability, in some of indices i.e., consecutive wet days (CWD) and Annual total rainy days (PRCPTOT) showed statistically mixed trends. The present study, therefore, indicates somewhat ambiguous trends in rainfall in Himachal Pradesh.

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Anthracnose disease dynamics of mango orchards in relation to humid thermal ratio under subtropical climatic condition

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ABSTRACT

Incidence and severity of mango anthracnose was studied during 2013, 2014 and 2015 for its relation with weather parameters. Twenty two mango orchards of cv. *Dashehari,* aged between 20-35 years in Lucknow district of Uttar Pradesh were selected for this study. The statistical analysis at different locations indicated highest incidence of 40.0, 29.2 and 29.6 per cent in three years respectively. Differences in disease severity were also observed among the years and within the orchards. Cooler months had high humid thermal ratio (HTR) values and warmer months mostly had low (1.2 to 3.5) HTR values. Significant positive correlation was found between HTR and anthracnose incidence and severity. The study inferred that humid thermal ratio may be used for prediction of the disease as a ratio of agroadvisory services to recommend timely protection measures to the farmers.

Key words: Anthracnose, weather parameters, humid thermal ratio, correlation, mango

Mango is widely grown in India across diverse climatic conditions and is impacted by several pests and diseases. Anthracnose disease of mango is one of the most important diseases to cause severe losses to the mango fruit and in turn economical yield of the orchard (Ploetz, 1999). The conidia of *Colletotrichum gloeosporioides* may cause direct infection of tender leaves, stems, flowers and fruits. The pre-harvest infection of the fruits causes severe post harvest rot, which is responsible for lowering the marketing value (Swamy, 2012). Pandey *et al.* (2012) and Kamle *et al.* (2013) had studied the incidence and phylogenetic correlation in mango. Ann *et al.,* (1994) observed that the weather parameters particularly rainfall, high relative humidity (RH) and higher temperatures favour the disease development. The amount, frequency and distribution of rainfall also significantly influenced the anthracnose incidence on mango fruits.

Environmental factors and phenological stages are crucial in the development of the disease. Weather extremities profoundly influence critical mango phenological stages. Rajan (2012) reported that temperature and rainfall are the most important factors impacting the phenology of the crop and in turn associated crop-weather-pest and disease dynamics. Research reports are available on the role of different key weather parameters like temperature, RH and rainfall on the disease prediction (Misra *et al.,* 2004; Saha, and Das, 2014). The ratio of temperature and RH was used for determination of extent of variability in the outbreak of leaf spot disease (Ijaz *et al.,* 2011). Based on four years field experimentation in Tikamgarh area of Madhya Pradesh, Gangwar *et al.* (2014) concluded that humid thermal ratio influence the leaf spot severity on groundnut. Based on these parameters around 72 per cent disease variability can be predicted. These studies may be helpful in delivering forewarning for adopting required control measures of pest and diseases (Saumi *et al.,* 2005). Information on the impact of relative humidity and temperature ratio, two most important factors influencing disease development in not available and has not been studied for anthracnose disease. Hence, the present investigations were set out to assess the anthracnose dynamics using humid thermal ratio, based on datasets from 22 fixed plot mango orchards in Lucknow district.

MATERIALS AND METHODS

The present study was conducted in Lucknow district (26.54^{0}N Latitude, 80.45^{0}E Longitude and 127 m above mean sea level), Uttar Pradesh, India in 22 mango orchards (20-35 years) of cv. *Dashehari*. All these orchards were designated as fixed plots, which had trees planted at 10×10 m distance. Mango anthracnose disease incidence and severity appraised on these orchards during three consecutive years i.e. 2013, 2014 and 2015. Each orchard had at least 25 trees. Data on anthracnose were recorded on weekly basis from five randomly selected trees in four direction of the tree. Disease incidence and severity recorded from 10 shoots in each direction of tree. Disease incidence was calculated on the basis of total number of leaves and panicles observed on a tree and the number of leaves having disease symptoms. Incidence and severity was recorded from 1st SMW to 52nd SMW during 2013 and 2014; however for 2015, it is up to 30th SMW (July). These data were used for further analysis and discussion.

$$\text{Disease incidence}(\%) = \frac{\text{Number of diseased leaves observed}}{\text{Total number of leaves observed}} \times 100$$

The disease severity was recorded as the per cent infected area and it was converted into 0-4 scale, where, 0 = nil, 1 = 1-5%, 2 = 5.1-10%, 3 = 10.1-20%, 4 = above 20%. Per cent disease ratio was calculated as follows:

$$\text{PDI} = \frac{\text{Sum of all numerical ratings}}{\text{No. of leaves observed} \times \text{Maximum rating}} \times 100$$

The experimental area was characterized as subtropical with hot dry summers and cold winters. Daily weather data of temperature (maximum and minimum), relative humidity (morning and evening), rainfall, wind speed, bright sunshine hours and evaporation rates were recorded in the agro meteorological observatory located within the experimental site. Further, weather data was used to calculate humid thermal ratio using following formulae (Jhorar *et al.,* 1992).

$$HTR = RH_{mean} / T_{mean}$$

where, HTR is humidity thermal ratio, RH_{mean} is mean relative humidity and T_{mean} is mean temperature.

Disease dynamics was plotted against years. Year wise histographic distribution of anthracnose was carried out by SPSS package (Version 16.0). Linear regression equations were generated by considering weather parameters as independent variables and anthracnose as dependent variables. Statistical significance of Pearson's correlation coefficients between dependent and independent variables under the study was drawn using t test significance. Functional relationship between HTR and anthracnose was carried out using MS Excel software.

RESULTS AND DISCUSSION

Incidence and development of anthracnose on mango

The statistical analysis showed wide variations in mango anthracnose incidence across 22 orchards and three years (Table 1). The analysis of mean incidence across the three consecutive years revealed that the highest incidence was 40.0, 29.19 and 29.67 per cent. During the year 2013, highest anthracnose incidence (40.0±0.80%) was recorded in Hafizkhera (Fixed plot-I) followed by 39.27±0.73 per cent in Navipana (Fixed plot-I) orchard, while lowest one (34.65±0.57) was recorded in NB Dhanewa (Fixed plot-I). Similarly, lowest value of 23.96±1.20 per cent incidence was observed in Allupur (Fixed plot-I) and highest as 29.19±1.63 in CISH Block III followed by 28.96±1.67 in CISH Bolck II during the year 2014. The corresponding values were 26.27±0.29, 29.67±0.35 and 29.47±0.42 per cent in Allupur, CISH Block II and Hafizkhera (Fixed plot-I) respectively during the year 2015 (Table 2). It was further noticed that some of the orchards had lowest incidence and coefficient of vartions between 9.6 to 17.3 per cent in 2013 and 2015, in contrast to 2014, had higher CV values (28.91 to 35.92 per cent) of disease incidences.

Differences in disease severity were also observed among the three years (Table 2). The progressive changes in disease severity were much more in the third year as compared to first and second year (Table 2). Highest severity of 14.42±0.14 PDI was observed in Navipana (Fixed plot I) followed by 14.39±0.18 PDI in Navipana Fixed plot II with lowest in NB Dhanewa fixed plot I (12.29±0.08 PDI) during 2013. During 2014 year, Hafizhkhera Fixed plot I had highest PDI 13.62±0.70 while lowest was found as 10.25±0.38 in Allupur Fixed plot II. A maximum of 18.81±0.33 PDI was recorded in CISH Block II followed by 18.57±0.33 PDI in Hafizhkhera (Fixed plot I) and with the lowest as 15.89 PDI in Allupur (Fixed plot II). The histographic representation indicated that the mean value of mango anthracnose incidence was 37.16 per cent during 2013 (n = 1144), while in next two years, it was 26.43 per cent (n = 1144) and 28.22 per cent (n = 660). The frequency distribution further explained that the anthracnose incidence was higher in the range of 30 to 40 per cent during 2013 while during 2014 and 2015, it was widely distributed with 20 to 30 per cent and the highest frequency level of 50 to 100 per cent. To realize the wide variation in the anthracnose severity, histographic analysis revealed that the mean of anthracnose severity was 13.46, 12.15 and 17.30 PDI during 2013, 2014 and 2015 respectively.

Variations in disease incidence and severity are a function of exited microclimatic conditions within the crop canopy and also across years. Shew *et al*. (1988) found that the genotypes with partial resistance to late leaf spot proved

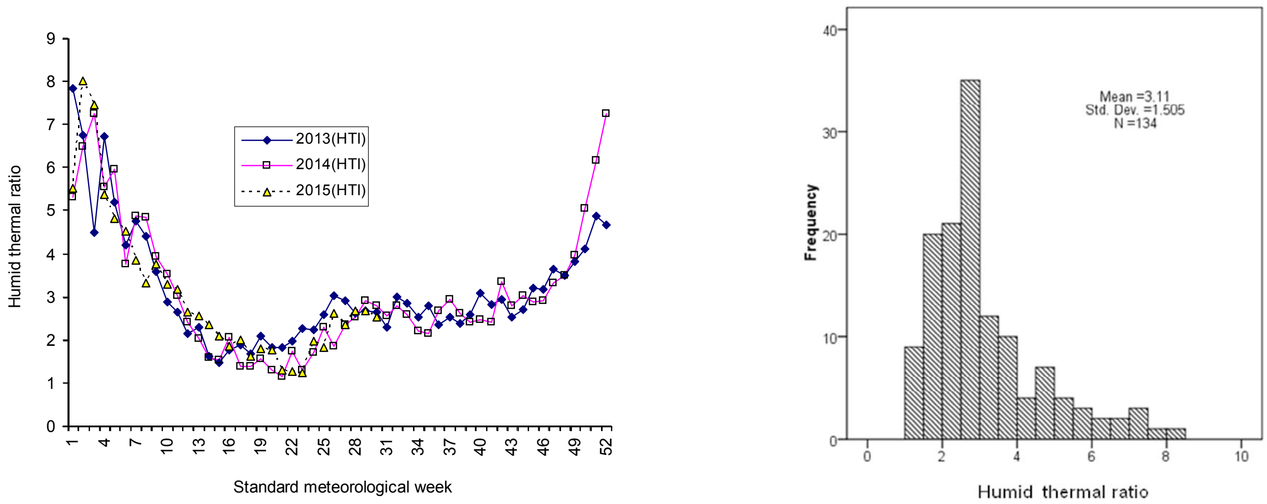

Fig. 1: Variations in humid thermal ratio during the study periods and its frequency distribution

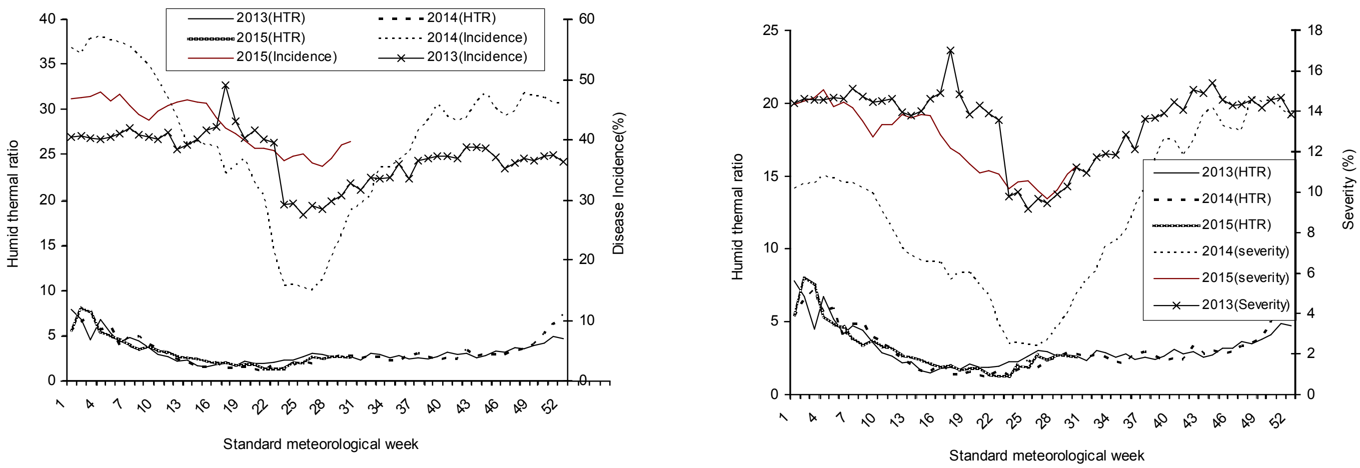

Fig. 2: Dynamics of incidence and severity of disease

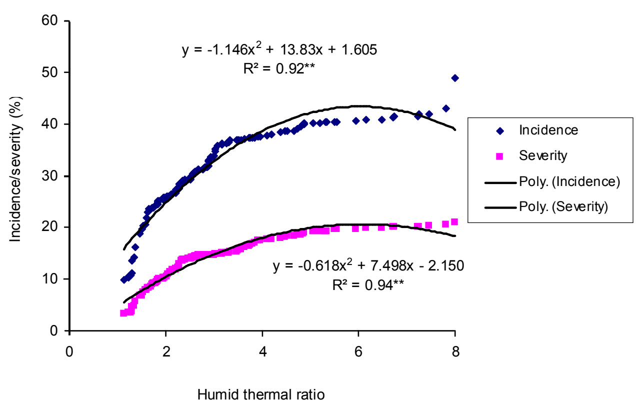

Fig. 3: Correlation between incidence and severity of disease with HTR

most sensitive to high temperatures. Ijaz *et al.* (2011) reported *Cercospora* leaf spot prediction based on humid thermal ratio and forecasted 80-94% in susceptible genotypes and 64-93% in partially resistant genotypes during 2003, 2004 and 2005 respectively.

Relationship between humid thermal ratio with anthracnose incidence and development

Results revealed that the estimated humid thermal ratio widely varied during the year and variations across the years were also observed (Fig. 1). Values ranged between 3.0- 8.0 during January – March months. It indicates that

Table 1: Incidence and severity (%) of anthracnose disease of mango.

	Incidence						Severity					
	2013		2014		2015		2013		2014		2015	
Orchard	Mean±SEm	CV(%)	Mean±SEm	CV(%)	Mean±SEm	CV(%)	Mean±SEm	CV(%)	Mean±SEm	CV(%)	Mean±SEm	CV(%)
Malihabad (Fixed I)	36.5±0.55	14.7	26.3±1.12	28.91	28.1±0.36	11.7	13.2±0.09	16.56	12.1±0.53	43.29	17.2±0.27	16.4
Malihabad (Fixed II)	36.1±0.52	14.3	25.7±1.08	29.17	28.1±0.42	12.6	13.0±0.10	17.28	11.9±0.58	46.08	16.7±0.30	17.9
Navipana (Fixed I)	39.3±0.73	15.7	26.6±1.34	31.45	28.0±0.24	9.6	14.4±0.14	18.79	12.1±0.58	45.11	17.1±0.16	12.8
Navipana (Fixed II)	38.5±0.71	15.8	27.5±1.41	31.09	28.9±0.40	12.0	14.4±0.18	21.13	12.9±0.66	45.47	18.1±0.28	16.0
Methe Nagar (Fixed I)	36.9±0.73	16.7	26.0±1.40	32.81	28.1±0.35	11.5	13.00±0.11	18.21	11.8±0.58	46.52	17.1±0.28	16.9
Methe Nagar (Fixed II)	37.0±0.50	13.8	27.1±1.30	30.27	29.0±0.43	12.4	13.2±0.08	15.80	12.4±0.62	45.52	17.9±0.30	16.9
Hafizkhera (Fixed I)	40.0±0.80	16.1	28.5±1.54	31.34	29.7±0.35	10.9	14.9±0.20	21.73	13.6±0.70	44.32	18.6±0.33	16.9
Hafizkhera (Fixed II)	36.1±0.49	13.9	25.0±1.11	30.33	26.6±0.27	10.7	12.7±0.08	16.19	10.9±0.40	41.57	16.2±0.24	16.5
Mahmood Nagar (Fixed I)	38.2±0.84	17.3	26.3±1.24	30.50	28.1±0.37	11.9	14.1±0.17	21.31	12.0±0.53	43.47	16.9±0.30	17.8
Mahmood Nagar (Fixed II)	36.7±0.68	16.2	25.9±1.20	30.38	28.2±0.33	11.1	13.0±0.10	17.36	11.7±0.48	42.43	17.5±0.25	15.6
Kakori (Fixed I)	37.3±0.56	14.5	26.1±1.34	31.97	27.5±0.37	12.2	13.4±0.10	17.32	11.9±0.50	42.78	16.6±0.25	16.5
Kakori (Fixed II)	37.5±0.52	13.8	26.9±1.24	29.86	28.5±0.35	11.3	13.6±0.11	17.99	12.3±0.51	41.83	17.3±0.25	15.8
Ulrapur (Fixed I)	36.0±0.55	14.9	25.9±1.45	33.54	28.4±0.28	10.2	13.0±0.07	14.16	11.9±0.62	47.85	17.6±0.20	13.8
Ulrapur (Fixed II)	38.2±0.74	16.2	26.9±1.79	35.92	28.9±0.69	15.7	13.8±0.13	18.87	12.8±0.97	55.52	18.1±0.52	21.7
Kanar (Fixed I)	37.2±0.69	16.0	25.5±1.35	32.85	28.0±0.32	11.1	13.5±0.12	18.53	11.4±0.49	44.21	16.8±0.20	14.6
Kanar (Fixed II)	36.4±0.58	15.1	25.8±1.38	32.84	27.9±0.50	13.8	13.2±0.10	17.54	11.8±0.57	46.22	16.9±0.34	18.7
NB Dhanewa (Fixed I)	34.6±0.57	15.7	25.8±1.16	30.06	27.9±0.51	14.0	12.3±0.08	17.00	12.1±0.71	50.18	17.0±0.37	19.7
NB Dhanewa (Fixed II)	36.3±0.54	14.5	25.7±1.12	29.61	27.93±0.29	10.6	13.2±0.09	16.66	11.4±0.45	42.37	17.1±0.19	13.8
CISH Block-III (Fixed I)	38.8±0.71	15.7	29.2±1.63	31.56	29.0±0.29	10.2	14.3±0.15	19.54	13.8±0.78	46.28	17.9±0.19	13.4
CISH Block-II (Fixed II)	38.2±0.59	14.5	28.9±1.67	32.17	29.5±0.42	12.1	14.0±0.14	19.41	13.9±0.75	45.02	18.8±0.33	16.6
Allupur (Fixed I)	36.0±0.64	16.1	25.7±1.42	33.40	28.3±0.34	11.3	13.3±0.09	16.24	11.9±0.55	44.70	16.9±0.20	14.5
Allupur (Fixed II)	35.2±1.22	22.6	23.9±1.20	32.95	26.3±0.29	11.3	12.5±0.17	23.57	10.2±0.38	43.53	15.9±0.22	16.0

cooler months had higher HTR as the temperature in the denominator was lower during these periods. Phenological events like vegetative flushes and initiation of flowering were occurred during these months. As the phenological stage advanced and with the onset of higher temperature during April to October, the ratio started declining and mostly ranged from 1.2 to 3.5. The frequency distribution further showed that the mean value of HTR was 3.11 (n = 134). Towards the end of year, during cooler months of November and December, the ratio values started increasing once again. The lowest and highest values of the humid thermal ratio were 1.47 to 7.82 during the year 2013, 1.13 to 7.25 during 2014 and 1.23 to 8.0 in the third year. The pictorial presentation of HTR with disease incidence and severity (Fig. 2) depicts that both the incidence and severity exhibited decreasing trend in the 2014 as compared to other years between 20 to 30 standard meteorological weeks. The probable reason is that the rainfall was almost absent i.e. weekly average rainfall was only 0.4 to 12.4 mm between 24 to 33 SMW during 2014 while in 2013, in each week there was a sufficient rainfall (weekly average of 1.29, 15.47, 23.34, 6.51, 11.14, 7.0, 13.29, 13.71 and 21.74 mm rainfall received). Likewise in 2015 year also sufficient rains occurred, which could have contributed to the severe infection and development of the anthracnose. Not only rainfall, but RH_{min} was also lower in 2014. Thus, rainfall plays a major role in the incidence and severity of this disease on mango. Kaur *et al.* (2007) also observed that relative humidity (RH), rainfall and number of rainy days are the most important weather parameters indicating favourable role in the development of karnal bunt disease. Rainfall accompanied by high RH contributing major part for karnal bunt disease in wheat and it was estimated that the variability of occurrence of karnal bunt in the Karnal zone of Haryana state was up to 76% with the help of weather parameters (Singh *et al.,* 2013). Gangwar *et al.* (2014) concluded that maximum disease severity of leaf spot in groundnut was observed when the HTR values were near to 3.0 during 2011 while in the next year; higher values observed when mean temperature was 26°C. In such a situation progression of the disease was restricted. Actually, biotic and abiotic factors predominantly plays havoc role at critical phenological stages of mango as it grow in open field conditions. Crop weather interaction and associated disease dynamics are thus become vulnerable under the ambit of ambient temperature, relative humidity and precipitation. Jensen and Boyle (1965) reported that RH was most favourable for leaf spot development. The humid thermal ratio/ratio was best known and applied for disease risk assessment world over and in India too (Wangikar and Shukla, 1977; Baker *et al.,* 2000; Jhorar *et al.,* 1992; Mavi *et al.,* 1992). Lin *et al.* (2015) observed that the pest and disease dynamics in mango are profoundly influenced by the biotic and abiotic factors, even in an identical environment and also suggested that relative humidity and temperature are the most crucial factor. Thus, in this study we have considered the humid thermal ratio to assess the anthracnose disease dynamics. The significant positive correlation was found between HTR and anthracnose incidence and severity during all the years. The pooled data also showed significant positive correlation between humid thermal ratio and disease incidence and severity. The best fit polynomial second order regression had explained up to 92-94 per cent of variations in incidence and severity (Fig. 3). Hence, this clearly indicates that humid thermal ratio may serve the purpose of forecasting and agroadvisory for timely control measures of the disease.

CONCLUSION

From the present study it is inferred that weather parameters particularly rainfall, temperature and relative humidity plays a pivotal role on the incidence and variations in mango anthracnose across the years and orchards. The disease dynamics were lower in 2014 due to absence of sufficient rainfall while in other two years, because of predominance and occurrence of sufficient rainfall, incidence and severity of mango anthracnose was higher. Across different orchards, incidence and severity varied mainly because of the microclimatic situation exited thereof and the control measures adopted by the farmers. Positive correlation of anthracnose incidence and severity to humid thermal ratio suggested that this ratio may explain the variations in anthracnose dynamics to a greater extent.

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Effect of epidemiological factors on the severity of stripe rust of wheat caused by *Puccinia striiformis*

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ABSTRACT

The effect of epidemiological factors on the severity of stripe rust in cv. PBW 343, under early sowing conditions were studied during 2013-14 and 2014-15, *rabi* seasons. The disease was first appeared in 1st standard meteorological week (SMW) when the crop stage was at 73 days after sowing. Sharp increase in disease severity was observed during 6th to 8th SMW due to the conducive weather conditions which prevailed during the previous fortnight. The meteorological parameters like maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure and micro meteorological parameters (canopy temperature and soil temperature) had significantly positive correlation with the disease severity in the tested wheat variety, whereas, maximum relative humidity had significant negative correlation. Rainfall had moderately positive correlation with the disease severity. The models generated through stepwise multiple regression analysis revealed that thermic, and hydric variables contributed significantly for the variance in disease severity. Among the three principal components, Pc_1 that was contributed by various epidemiological factors (thermic and biological) accounted for maximum variance in disease severity followed by Pc_2 (light variables) and Pc_3 (hydric variables).

Key words: Stripe rust, epidemiology, correlation, stepwise regressions, wheat

By considering the limited resources, production challenges, biotic stresses and aberrations in weather parameters, it is a big challenge to feed the ever increasing population, approximately 125 million tonnes of wheat is estimated to be required by 2030. Stripe rust caused by *Puccinia striiformis* Westend. is reported as the most destructive one, though earlier it was considered as least damaging but due to changing climatic conditions, has emerged as major disease in last decade (Fu *et al.,* 2009). The disease occurs in areas having cool and moist weather conditions during the wheat growing season (Samborski, H.A.S., 2013). The disease is continually extending the geographical limits, showing movement towards warmer areas due to the appearance of more aggressive pathogen strains, having affiliation towards higher temperatures (Hovmoller *et al.,* 2008; Milus *et al.,* 2009). In India, stripe rust is confined to the cooler regions of the North-West (Punjab, Haryana, U.P. and Jammu and Kashmir) and in Nilgiris hills of South India and is responsible for considerable yield losses (Nagarajan *et al.,* 1984; Kumar *et al.,* 1989). Weather parameters such as temperature, relative humidity and rainfall are the main predisposing factors in stripe rust incidence (Schroder and Hassebrauk, 1964). The plant diseases are a complex interrelationship between weather, amount of inoculum, rate of disease development and host response, therefore a reliable forecasting system is required if management strategies are to be made more effective and economical in reducing yield losses. Keeping this in view, the present study was conducted during *rabi* seasons of 2013-14 and 2014-15 to study the effect of various metrological factors on the severity of stripe rust of wheat.

MATERIALS AND METHODS

The experiments were conducted at the University Research Farm, Chatha (32° 43' N, 74° 54'E). Based upon the response against disease cv. PBW 343 (highly susceptible) was selected for the study which was sown in 9 m^2 plots during last week of October (44 SMW) under early sowing conditions. The experiments were laid out in randomized block design (RBD) with four replications, having row to row spacing of 22.5 cm. The urediniospores spore dust of mixed pathotypes of *Puccinia striiformis* was collected from Regional Rust Research Centre, Indian Institute of Wheat and Barley Research (ICAR), Flowerdale, Shimla, during Oct., 2013. The inoculums suspension for inoculating test variety was prepared by suspending the

Table 1: Effect of meteorological parameters on the severity of stripe rust of wheat under early sowing conditions

SMW	PBW 343	$C_{Temp.}$ (^{0}C)	$T_{Max.}$ (^{0}C)	$T_{Min.}$ (^{0}C)	$RH_{Max.}$ (%)	RH_{Min} (%)	M_{Wv} (km h^{-1})	Vp_{Mor} (mmHg)	$Vp_{Evn.}$ (mmHg)	SS (hr)	Rainfall (mm)	$CC_{Morn.}$ (okta)	CC_{Evn} (okta)	S_{Temp} (^{0}C)
1st	1.00	11.7	17.5	5.0	92.5	59.0	1.6	8.2	9.9	2.9	0.0	3.5	6.0	11.4
2nd	2.83	13.0	14.7	5.8	94.0	68.5	2.0	8.3	9.3	0.8	0.6	6.5	5.0	11.8
3rd	6.50	14.4	15.7	4.3	95.0	71.0	4.8	7.3	10.1	7.2	0.0	0.5	0.5	11.6
4th	10.83	16.0	16.0	7.9	91.5	75.0	1.6	9.3	11.0	0.0	5.0	3.0	5.0	13.3
5th	20.00	17.5	20.6	4.6	91.5	50.5	2.0	9.4	12.1	4.7	0.0	2.0	1.5	13.2
6th	26.67	18.0	19.4	10.2	82.0	64.0	3.3	11.0	12.5	3.8	0.0	6.5	3.0	13.7
7th	46.67	21.0	22.6	6.1	93.0	48.5	2.1	10.7	12.8	6.2	0.0	2.5	2.5	14.9
8th	63.33	16.0	24.1	8.8	96.0	57.0	1.2	14.5	16.5	6.9	0.0	4.5	1.5	15.7
9th	68.33	17.4	17.5	11.7	88.5	77.0	1.9	13.3	14.8	0.5	0.0	5.0	5.0	14.8
10th	71.67	18.2	21.5	9.3	89.5	54.0	3.0	12.4	12.3	5.9	14.6	2.0	2.5	15.1
11th	75.00	17.4	22.7	9.4	81.0	52.0	2.2	11.8	13.7	4.7	9.8	4.0	4.0	16.8
12th	81.67	21.7	27.5	11.7	87.0	46.5	2.1	15.5	15.5	6.8	0.0	2.0	0.5	19.9
13th	85.00	22.6	24.0	14.7	83.0	72.0	5.8	14.5	14.1	2.2	3.7	5.5	5.0	20.9
14th	86.67	25.7	27.0	12.1	82.0	47.5	5.4	8.8	15.0	9.8	18.7	1.0	0.0	20.8

C_{Temp} = Canopy temperature, T_{Max} = Maximum temperature, $T_{Min.}$ = Minimum temperature, $RH_{Max..}$ = Maximum relative humidity, $RH_{Min.}$ = Minimum relative humidity, $M_{Wv.}$ = Mean wind velocity, $Vp_{Mor.}$ = Morning vapour pressure, $Vp_{Evn..}$ = Evening vapour pressure, SS = Sunshine, $CC_{Morn.}$ = Morning cloud cover, $CC_{Evn.}$ = Evening cloud cover, $S_{Temp.}$ = Soil temperature

inoculum dust in sterile distilled water (95 ml) to which 5 ml of Tween-20 was added (Broers and Lopez-Atilano, 1994). The field was irrigated frequently to maintain adequate moisture conditions for the buildup of disease. The effect of different epidemiological factors *viz.*, minimum temperature, maximum temperature (^{0}C), maximum relative humidity, minimum relative humidity (%), rainfall (mm), soil temperature (^{0}C), canopy temperature (^{0}C), cloud cover (Okta), wind speed (km/h), sunshine hours (hrs/day), and vapour pressure (mmHg) were studied on the development of stripe rust on the PBW 343. The metrological data were collected from Agro-meteorological section of the University. The canopy temperature was recorded with infrared thermometer (Ramson make) and soil temperature with soil thermometer (Japson make). From the last week of December onwards the plants were monitored regularly to observe the initial foci of *Puccinia striiformis*. Disease severity (per cent infection) was recorded using modified Cobb's scale (Peterson *et al.*, 1948) on randomly tagged plants (4/plot). The severity of stripe rust was recorded starting from the Ist to 14th SMW. Correlation and stepwise regression analysis were conducted using SPSS 16 (Jamshed *et al.* 2008). The epidemiological and disease severity data of the selected wheat variety were further subjected to Principal Component Analysis (Xi *et al.* 2013).

RESULTS AND DISCUSSION

Effect of meteorological parameters

During both the seasons (2013-14 and 2014-15) under early sowing dates, primary infection appeared in Ist SMW (2th Jan. 2013 and 4th Jan. 2014, respectively) in cv. PBW 343 having severity of 1.0 per cent when the crop was at jointing growth stage (73 days after sowing) and the corresponding weather parameters (before one-week) having maximum temperature of 17.5^{0}C, minimum temperature of 5^{0}C, maximum relative humidity (RH) of 92.50 and minimum of 59 per cent, mean wind velocity of 1.6 km h^{-1}, vapour pressure (morning 8.2 mmHg and evening 9.9 mmHg), sunshine (2.9 h day^{-1}), cloud cover (morning 3.5 and evening 6.0 okta), soil temperature (11.4^{0}C) and canopy temperature (11.7^{0}C) (Table 1).

The disease gradually progressed with the age of crop and increased sharply from 26.6 to 63.3 per cent in PBW 343, during 6th to 8th SMW when the crop was at heading to milk stage (108 to 122 DAS), with maximum temperature of 19.4 to 24.1^{0}C, minimum temperature of 10.2

Table 2: Correlation of meteorological parameters with the severity of stripe rust of wheat

Meteorological parameters	PBW 343
$T_{Max.}$	0.830
$T_{Min.}$	0.828
$RH_{Max.}$	-0.586
$RH_{Min.}$	-0.361
$M_{Wvv.}$	0.312
$Vp_{Morn.}$	0.754
$Vp_{Evn.}$	0.867
SS	0.396
Rainfall	0.502
$C_{Temp.}$	0.779
$CC_{Morn.}$	-0.075
$CC_{Evn.}$	-0.290
$S_{Temp.}$	0.899

Values in bold are highly significant at (p=0.05)

to 8.8^{0}C, maximum RH of 82 to 96 per cent, minimum RH of 64 to 57 per cent, mean wind velocity of 3.3 to 1.2 km h^{-1}, vapour pressure (morning 11 to 14.5 mmHg and evening 12.5 to 16.5 mmHg), sunshine (3.8 to 6.9 h day^{-1}), cloud cover (morning 6.5 to 4.5 and evening 3.0 to 1.5 okta), soil temperature (13.7 to 15.7^{0}C) and canopy temperature (18 to 16^{0}C).

At the maturity stage (164 DAS) in 14th SMW, maximum disease severity of 86.6 per cent was recorded in PBW 343 with maximum temperature of 27^{0}C and minimum of 12.1^{0}C, maximum RH of 82 and minimum of 47 per cent, mean wind velocity of 5.4 km h^{-1}, morning vapour pressure of 8.8 and evening of 15 mmHg, sunshine of 9.8 h day^{-1}, rainfall of 18.7 mm, morning cloud cover of 1.0 okta, soil temperature of 20.8^{0}C and canopy temperature of 25.7^{0}C.

Prevalence of conducive environmental conditions *viz*., low temperature (11.2^{0}C), high maximum RH (92%), with continuous cloud cover (5.0 okta) along with phenological vulnerable stages of host (jointing, stem elongation and tillering) were found favourable for the initiation of primary infection of stripe rust, which was found to be in confirmation with the findings of Stubbs (1967) and Chen *et al.* (2014) who reported that stripe rust frequently occurred in the areas having cool and moist conditions with low temperature of 7 to 12^{0}C. Activities of *P. striformiis* such as germination, penetration and development were hindered due to rise in temperature during April which prevented further disease development as a result of heat and dryness (Salman *et al.,* 2006; Lal *et al.,* 2008).

Correlation between disease severity and meteorological parameters

Under early sowing dates, in PBW 343, temperature (maximum and minimum), vapour pressure (morning and evening), canopy temperature and soil temperature had a significantly positive correlation with the disease severity having correlation co-efficient (R) values of 0.83, 0.83, 0.75, 0.87, 0.78 and 0.90, respectively, followed by rainfall (R=0.50) which was positively but moderately correlated. Whereas, maximum RH (R=-0.59) had a significant but negative correlation with the disease severity (Table 2). Ahmed *et al.* (2010) observed that stripe rust severity had strong correlation with maximum temperature, minimum temperature and sunshine hours having 'R' value of 0.45, 0.3 and 0.47, respectively. Christensen *et al.* (1993) also recorded that temperature in January and February was significantly correlated with severity of stripe rust of wheat.

Stepwise regressions

In PBW 343, under the early sowing dates, the regression equation developed was highly significant in predicting the severity of stripe rust (Table 3). Among different explanatory variables, 92.6 per cent variation was explained by the cumulative effect of evening vapour pressure, morning vapour pressure and rainfall. Thereby predicting that an increase/decrease in disease severity by 6.32 per cent per week by per unit increase/decrease in evening vapour pressure, if all the other predictors remained constant (95 % CI from 1.13 to 11.50 %). Whereas, 5.61 per cent increase/decrease in disease severity was predicted per week by per unit increase/decrease in morning vapour pressure if all the other predictors remained constant (95 % CI from 1.28 to 3.54%). The developed regression model was validated with independent data set in cv. Agra local which showed that showed that 97.4 per cent variation was explained by commutative effects of evening vapour pressure, rainfall, morning vapour pressure and canopy temperature. Observed versus prediction of disease severity values showed good association in PBW 343 and Agra Local (R^2=0.92 and 0.93). The lower tolerance (<1) and VIF (<10) showed the least multi-collinearity (inter correlated effect). Thermal and harydic variables were responsible for 94 to 99 per cent and 91 to 98 per cent variation in causing leaf rust severity in wheat, respectively (Jamshed *et al.,* 2008). Since, environment is a complex system, it is influenced by many

Table 3: Stepwise regression of meteorological parameters with the severity of stripe rust of wheat

Variety	Stepwise Regression Equation	R^2	F value	95% C I Lower-upper	Tolerance	VIF
PBW 343	$Y = -106.12 + 6.32 X_6 + 5.61 X_3 + 2.41 X_5$	0.926	41.9	X_6=1.13-11.50	.306	3.264
				X_3=1.28-3.54	.832	1.202
				X_5=1.34-9.88	.317	3.154
Agra Local	$Y = -102.44 + 3.13 X_6 + 1.90 X_5 + 5.06 X_3 + 2.57 X_4$	0.974	41.8	X_6 =-1.86-8.14	.233	4.300
				X_5=.84-2.96	.669	1.494
				X_3=1.46-8.66	.315	3.172
				X_4 =.41-4.72	.425	2.351

Y = Disease severity, $Vp_{Morn.}$ = (X_3), C_{Tmp}.= (X_4), Rainfall= (X_5), Vp_{Even} = (X_6)

Table 4: Principal component analysis of meteorological parameters of stripe rust of wheat

Meteorological parameters	Community	Pc_1	Pc_2	Pc_3
Agra Local	.964	.908	.192	.322
PBW 343	.952	.926	.169	.256
$T_{Max.}$	.934	.801	.528	.117
$T_{Min.}$	.946	.864	-.246	.374
$RH_{Max.}$	.701	-.554	.146	-.611
$RH_{Min.}$	.701	-.278	-.785	.079
$M_{Wvv.}$	.721	.117	.110	.834
$Vp_{Morn.}$	.911	.902	-.119	-.289
$Vp_{Evn.}$	.889	.911	.225	-.092
SS	.912	.202	.917	.174
Rainfall	.661	.221	.250	.742
$C_{Temp.}$	.825	.693	.349	.473
$CC_{M orn.}$	.730	.173	-.807	-.221
$CC_{E vn.}$	.807	-.151	-.882	-.080
$S_{Temp.}$	.927	.859	.198	.386
Variance (%)	—	59.49	16.55	9.28
Cumulative (%)	—	—	76.04	85.32

variables, where change in one leads to the change in another. Precipitation (rainfall) washes inoculum from the air, reduces light intensity, lowers temperatures and increases the probability of dew formation for several succeeding days, which favours disease development and spread (Eversmeyer and Burleigh, 1969).

Principal component analysis

Three principal components (Pc_1, Pc_2 and Pc_3) were generated, in which Agra Local and PBW 343, maximum temperature, minimum temperature, morning vapour pressure, evening vapour pressure, canopy temperature and soil temperature contributed maximum in principal component one (Pc_1) having coefficient values of 0.90, 0.92, 0.80, 0.87, 0.90, 0.91, 0.69 and 0.85, followed by minimum relative humidity, sunshine hours, morning cloud cover and evening cloud cover in Pc_2 having coefficient of -0.78, 0.92, -0.81 and -0.88, while, maximum relative humidity, mean wind velocity and rainfall contributed in Pc_3 having coefficient of -0.61, 0.83 and 0.74, respectively. Among the 85.32 per cent cumulative variance explained by epidemiological factors, Pc_1, accounted for 59.49 per cent, followed by 16.55 and 9.28 per cent variance by Pc_2 and Pc_3, respectively which was in confirmation with the findings of others workers who reported that temperature, moisture and light have major role in uredinial infection process and spread of the disease (Chen *et al.,* 2014).

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Effect of weather parameters on sporadic incidence of cucumber moth, *Diaphania indica* (Saunders) (Lepidoptera: Pyralidae) in bitter gourd ecosystem

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ABSTRACT

The field experiments were carried out to study the population fluctuation of Cucumber moth, *Diaphania indica* in bitter gourd and its relationship with different weather variables during *Kharif* seasons of 2014 and 2015 in Varanasi region. Weekly data on larval population of *D. indica* on bitter gourd were taken through simple random sampling whereas different abiotic parameters were obtained from the meteorological observatory of the institute. The results revealed that the *D. indica* population commenced from 31st SMW. The maximum population was recorded during 38th SMW (in 2014), during 39th SMW (in 2015). During September in both the years. The maximum, minimum and mean temperature, growing degree day, heliothermal unit and evaporation rate showed significant positive correlations with this sporadic pest where as a negative correlation was established with relative humidity, rainfall and wind velocity. A weather based prediction model has also been developed with different weather indices and pest incidence using weekly average value.

Keywords: *Diaphania indica, bitter gourd, abiotic factors, forewarning model*

Cucumber moth or pumpkin caterpillar, *Diaphania indica* (Saunders) (Lepidoptera: Pyralidae) is a sporadic pest of cucurbitaceous crops especially bitter gourd, cucumber, pointed gourd and gherkin. Light green larvae, with two prominent longitudinal dorsal whitish lines, feed chlorophyll portion of the leaves by webbing them together. Damage is more severe when they feed the reproductive parts of the plants *viz*., flowers and young fruits. The larvae make characteristic holes on the fruits and feed inside it. The bored fruits become unfit for human consumption (Rai *et al*., 2014). Though this pest has been reported as the major pest of most cucurbitaceous crops world over (Ganehiarachchi, 1997), in India, particularly eastern part of Uttar Pradesh earlier it was considered as a minor pest of cucurbits. In last couple of years its infestation has become serious and observed in regular manner. Critical observation revealed that its infestation started from August and continued till November/December coinciding with the onset of winter with peak infestation during the September when crops like bitter gourd and cucumber are at their mid reproductive stage. During this period, the damage by this pest was so serious that chemical control was almost inevitable. Farmers of this region often used to apply around 5-7 rounds of synthetic insecticides to control this oligophagous pest. This practices have led to many fold problems like resistance to insecticides, resurgence of target insects and secondary pest outbreak in addition to insecticide residues in food and beverages, contamination of groundwater, adverse effect on human health, and wide spread killing of non-target organisms (Halder *et al*., 2012, 2013 and 2014).

The insect pest incidence is an outcome of interaction among host, insect and weather over a period of time. Different meteorological parameters *viz*., temperature, rainfall and relative humidity greatly influence the insect population (Siswanto *et al*., 2008). With this in view, the present investigation was aimed to elucidate the effect of different weather parameters on the population buildup of *D. indica* in bitter gourd ecosystem and also to develop a weather based prediction model for this emerging pest. This will be useful to take suitable control measures well in advance, thus reducing the excessive and unnecessary usage of insecticides, cost of cultivation as well as environmental hazards.

MATERIALS AND METHODS

The field experiments were carried out at experimental farm of ICAR-Indian Institute Vegetable Research, Varanasi (82°52' E longitude and 25°12' N latitude), Uttar Pradesh, India during *Kharif* seasons of 2014 and 2015. The experiment site comes under the alluvial zone of Indo-Gangetic plains having soils silt loam in texture and low in

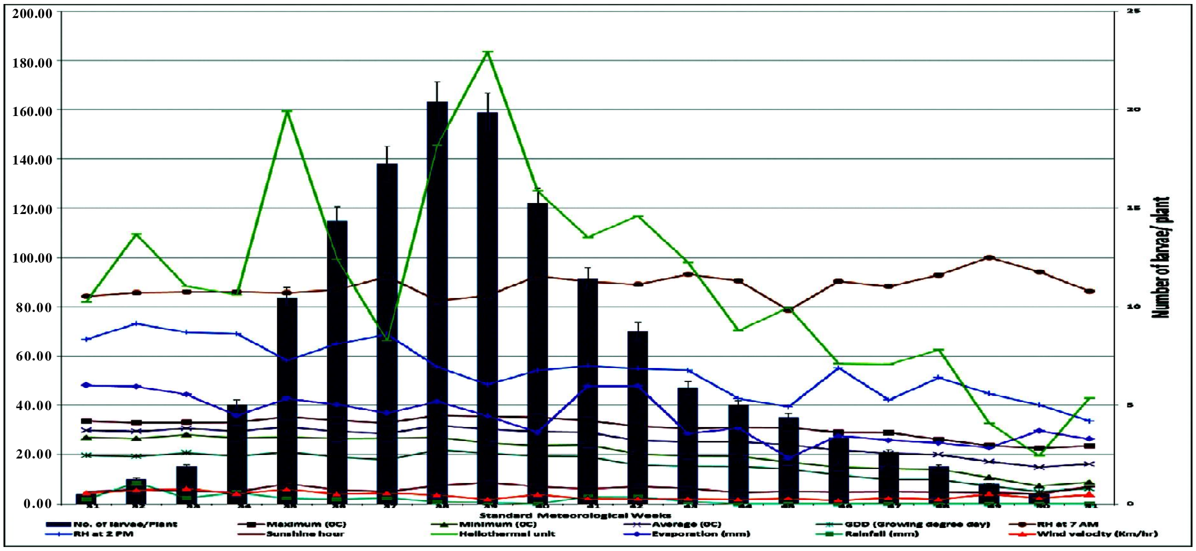

Fig.1 : Mean cucumber moth, *Diaphania indica* infesting bitter gourd and influenced by mean weather factors of the year 2014 and 2015.

organic carbon (0.43%) and available nitrogen (185 kg ha^{-1}). Mean weekly meteorological parameters recorded during cropping seasons 2014 and 2015 at IIVR meteorological observatory are presented in Fig. 1.

Seeds of bitter gourd were sown in a plot with plant to plant spacing of 50 cm and row to row distance 2 m with three replications during second fortnight of June of both the years. The recommended dose of fertilizers were applied. Hand weeding and irrigations were provided as required and usual crop husbandry measures were undertaken except plant protection measures.

Data recording

The regular monitoring for the insect incidence and subsequent damage on fruits as well as on tender buds was recorded during morning (in between 10 to 11 am). Ten randomly selected plants were tagged and data on number of larvae of *D. indica* per plant were counted at weekly intervals and expressed as number of larvae plant^{-1}. The data were recorded from just beginning when first symptom of *D. indica* was observed.

The data on weather parameters during the cropping periods were collected from meteorological observatory located in the institute. The weather parameters included are daily maximum temperature (T_{max}) (°C), daily minimum temperature (T_{min}) (°C), average daily temperature ($T_{average}$) (°C), average day relative humidity at 7.00 am and 2.00 pm (RH_{day}), bright sun shine hour, evaporation (mm), rainfall (mm) and wind velocity (km ph). The growing degree day (GDD) was calculated by subtracting base temperature (10°C) from average daily temperature whereas heliothermal unit (HTU) was derived by multiplying GDD with bright sunshine hours (Ghosh *et al*., 2015). The cumulative value of weather parameters were calculated by adding everyday value since the date of sowing.

Model development

All the independent variables were plotted against the dependent variable *i.e.*, number of larvae per plant. Since, growing degree day and heliothermal unit are derived from the base temperature were not considered for the final model development. The independent parameters which followed an exponential or power curve pattern are attempted and compared based on AIC (Akaike Information Criterion) (Aka ke, 1974) values. The AIC is expressed as:

$$AIC = -2ln\ (l(\tilde{\theta})) + 2q$$

Where $l(\tilde{\theta})$ was the model's likelihood i.e. the likelihood of the sample for the values estimated from the model parameters and q was the number of weather parameters estimated. A smaller value of AIC suggests a better model and thus exponential model was found the best suited in all the cases. Regression diagnostics were also conducted to validate the model. SAS software version 9.3 was used for statistical analysis following the standard procedure.

RESULTS AND DISCUSSION

It is evident (Fig. 1) that incidence of cucumber moth, *D. indica* on bitter gourd was started during 31st SMW in 2014 with 0.75 larva per plant and gradually increased and

Table 1: Correlation coefficient (r) of incidence of cucumber moth, *D. indica* with abiotic factors with pooled data (2014 and 2015)

Abiotic parameters	Pooled
Maximum temperature (T_{max})	0.568*
Minimum temperature (T_{min})	0.562*
Average temperature (T_{mean})	0.600*
Growing degree day (GDD)	0.600*
Relative humidity at 7 am (RH I)	-0.219
Relative humidity at 2 pm (RH II)	-0.050
Rainfall (RF)	-0.145
Sunshine hour (BSS)	0.230
Heliothermal unit (HTU)	0.480*
Evaporation (EP)	- 0.136
Wind speed (WS)	-0.038

* Significant at the 0.05 level (2-tailed)

reached maximum population during 38th SMW *i.e.,* third week of September with 24.25 larvae per plant. From fourth week of September onwards its population started declining with lowest 0.25 larvae $plant^{-1}$ was observed during 47th SMW (third week of November) and from last week of November onwards (48th SMW) coinciding with winter in this region no pest population was recorded. Similar trend was also followed during 2015. Highest larval population (19.25 larvae $plant^{-1}$) was observed during 39th SMW (last week of September). However, during 2015 pest incidence extended till 50th SMW (second week of December) due to delayed onset of winter in the region.

From Table 1 it is evident that maximum, minimum and average temperature had positive and significant correlation with the larval population in both the years and the corresponding correlation co-efficient (r) values were 0.568*, 0.562*, 0.600* respectively. Similar observation was also noted with growing degree day (r=0.600*) and heliothermal unit (r=0.480*). Sunshine had positive but non significant effect on larva population (r=0.230). Singh and Singh (1993) from Varanasi also reported increase in red spider mite, *Tetranychus cinnabarinus* (Boisd) population on okra associated with period of high temperature.

In contrast, relative humidity at 7 am and 2 pm, rainfall evaporation as well as wind speed had negative correlations with pest incidence but correlations were non significant. According to Patel *et al.* (2010), morning as well as average relative humidity was significantly and negatively associated with larval population of *Maruca vitrata*. Norris *et al.*, (2002) also recorded that rainfall significantly decreased the number of thrips remaining on the plants and number of rainy days increased, the numbers of thrips on the plants also decreased and the majority of thrips were washed off the plants within 30 minutes.

The stepwise forward selection method of model fitting was followed which begins with no variables in the model and then variables are added one by one to the model, and the F statistic for a variable to be added must be significant with improvement in coefficient of determination (R^2) of the model. The model thus obtained is given below.

$$Y = -66.16 + 2.22T_{max} + 1.07BSS - 1.51WSS + 0.36RH\ I - 0.25RH\ II + 0.82T_{min} + 0.09RF - 0.18EP \quad (R^2\text{-}0.79)$$

It is evident that the maximum temperature, sunshine hour, wind velocity, relative humidity, minimum temperature, rainfall and evaporation had direct influence (79%) on distribution and abundance of *D. indica* on bitter gourd.

It can be concluded that the information so generated from the present study could be useful to predict the population of cucumber moth, *D. indica,* an oligophagous and sporadic pest of cucurbitaceous vegetables, on at any given time and the developed model will be effective to initiate the suitable control practice to avoid the high yield loss.

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Crop weather relation in *kharif* rice for North-west Alluvial Plain Zone of Bihar

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ABSTRACT

Studies on crop weather relationship in rice were carried out over six *kharif* seasons from 2009 to 2014 at Pusa, Samastipur falling under North-west Alluvial Plain Zone of Bihar. Three rice varieties *viz. Rajendra Bhgwati, RW 3055 and Saroj* were grown under irrigated conditions with four sowing dates *viz.* 31 May, 15 June, 30 June and 15 July. The results revealed that accumulated heat units decreased with delay in sowing till crop reached tillering stage and increased thereafter till crop maturity. The grain yield was higher when maximum temperature (T_{max}) during heading phase remained between 32.2 and 32.6 ^{0}C and decreased appreciably when T_{max} was above 33 ^{0}C during this phase. Grain yield declines by 4.31 q ha^{-1} per 1 ^{0}C rise in T_{max} during heading stage due to reduction in 'pollen viability', resulting in greater spikelet sterility and subsequently lower yield. Except during tillering and flowering phases, the minimum temperature was negatively correlated with grain yield. Daily bright sunshine hours (BSH) of 7 to 8 hours during flowering phase led to enhanced grain yield. However, BSH of less than 7 hours resulted in decline of grain yield. Significant positive correlation was recorded between bright sunshine hours and grain yield.

Key words: Weather parameters, rice, grain yield, correlation, regression

Every crop/variety has its own optimal requirements of climatic variables like temperature, sunshine hour, rainfall etc. for potential yield. The responses and requirements of these variables which determine the growth and development of a plant in a given environment may vary from variety to variety within a species. In the same variety, they may also vary from one growth stage to another. The final biomass and yield of crops depend on the integrated effects of weather phenomena prevailing during different growth stages. Phenological development is the most important attribute involved in crop adaptation to varied gorwing environments. Both, the season length and the relative duration of key phenophases, are critical determinants of grain yield in field crops.

Rice is an important *kharif* crop in Bihar. The total area under rice in Bihar is about 3.18 million hectares with an average productivity of 25.3 quintals per hectare. There is a wide gap between average productivity and potential productivity owing to environmental factors, technology adoption and timely availability of inputs (Diwakar, 2009). Thus, to understand the crop phenology-weather interaction and to enhance the rice productivity in the state, the knowledge of the duration of different developmental phases and their association with yield determining weather factors is essential. With the help of crop weather relation studies, it is possible to show as to how the changes in rainfall amount, solar radiation and temperatures during different growth stages influence the crop productivity. Many researchers have studied crop weather relations and developed location specific regression models using weather variables for prediction of yields of rice (Agrawal *et al.*, 1980; Khan and Chatterjee, 1987, Devi *et al.,* 2013). In view of above, an attempt has been made here to assess the impact of weather parameters prevailing during different phases of growth on grain yield and thereby quantify the optimum weather conditions for maximizing the rice production at Pusa, Samastipur region under North-west alluvial plains of Bihar.

MATERIALS AND METHODS

The field experiments were conducted at Pusa Farm (25.8 ^{0}N, 86.7 ^{0} E and 52 m a.m.s.l), Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar over six *kharif* seasons from 2009 to 2014. The soil of the experimental site is clay loam in texture. The experiment was conducted with rice (varieties *Rajendra Bhgwati, RW 3055 and Saroj*) under irrigated condition and with adequate plant protection measures. The experiment was laid out in Randomized

Table 1: Phenophase durations and GDD requirements of *kharif* rice sown on different dates

Dates of sowing	Tillering	Heading	Flowering	Milking	Dough	Maturity
			Days after sowing			
31 May	47	89	109	116	133	142
15 June	48	88	103	109	121	131
30 June	48	85	98	104	119	126
15 July	49	85	96	106	124	118
			GDD (^{0}C day)			
31 May	955	1793	2175	2316	2622	2622
15 June	949	1748	2043	2156	2366	2366
30 June	979	1751	1941	2050	2307	2307
15 July	987	1676	1864	1965	2299	2299

Complete Block Design with four staggered dates of transplanting *viz.* 25 June, 10 July, 25 July and 10 August with three replications. The 25 days old seedlings were transplanted in rows 20 cm apart. The crop was uniformly fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} in the forms of urea, single superphosphate and muriate of potash, respectively. The occurrence of phenological events like tillering, heading, flowering, milking, dough and maturity were recorded from each plots and average dates of these phases were calculated and used for analysis.

The daily weather data on maximum temperature, minimum temperature and sunshine hours for the growing seasons were collected from the nearby Agromet Observatory, Dr. Rajendra Prasad Central Agricultural University, Pusa. Optimum weather conditions in terms of mean and ranges of maximum temperature (T_{max}), minimum temperature (T_{min}) and bright sunshine hours (BSH) during different crop growth phases were worked out based on daily weather observations.

The accumulated growing degree day (GDD) or heat unit was worked out for different phases of growth using the following equation (Nuttonson, 1955):

$$GDD=[(T_{max}+T_{min})/2-Tb]$$

Where, T_{max} = Maximum temperature of the day in ^{0}C

T_{min} = Minimum temperature of the day in ^{0}C

T_b = Base temperature in ^{0}C

In the present study, T_b considered was 8 ^{0}C following Alocilja and Ritchie (1991).

Simple correlation coefficients were computed between rice yield and weather parameters (Gomez and Gomez, 1976). The best-fit regression equations between rice yield and weather parameters occurring at different phases of growth were developed (Draper and Smith, 1966) to examine the rice-weather relationships.

RESULTS AND DISCUSSION

Phase duration and heat unit requirements

The duration of various phenophases of rice based on six crop season observations presented in the Table 1 revealed that there was a lot of variation in days required to attain different phases when the crop is grown under different micro-environmental conditions. The first three dates could be considered as normal sowing window for rice in the region, whereas 15 July represents late sowing of the crop. The results revealed that there was a decrease in duration of different growth phases with delay in sowing except the tillering phase. The crop sown on 15 July required 2 days more to attain maximum tillering stage than that sown on 31 May. However, the duration required to attain 50% flowering in 31 May and 15 July sown crop were 109 and 96 days, respectively. The crop sown on 31 May attained maturity in 142 days, while crop sown on 31 July reached maturity in 119 days. Kobayashi *et al.* (2010) concluded that higher air temperature and incident radiation tend to advance anthesis in rice. Such variation in durations of different phenophases of the crop may have been due to changes of sowing dates, which led to early or delayed fulfillment of thermal requirements to attain a particular phenophase.

While considering the accumulated GDD (Table 1) required for reaching different phenophases, it was observed that similar pattern like that of phenophase durations was noticed at all phenophases. The accumulated GDD to reach

Table 2: Correlation coefficients of weather parameters at different phenophases with grain yield of rice

	Growth phases					
Weather parameters	Tillering	Heading	Flowering	Milking	Dough	Maturity
T_{max}	0.15	-0.53**	0.75**	0.14	0.07	0.01
T_{min}	0.25	-0.12	0.15	-0.02	-0.11	-0.12
T_{mean}	0.12	0.08	0.28	0.46*	0.62**	0.52**
BSH	-0.09	-0.35	0.81**	0.12	0.10	0.36

* Significant 5 % level, ** Significant 1 % level

tillering decreased with delay in sowing, whereas, the accumulated GDD for attaining other growth phases increased. As compared to 15 July sown crop, the 31 May sown crop availed of more GDD for attaining 50 % flowering stage and the respective GDD were 1864, 2175 and 1864 ^{0}Cday, respectively. At maturity, the accumulated GDD were 2622, 2366, 2307 and 2299 ^{o}Cday for 31 May, 15 June, 30 June and 15 July sown crops, respectively. The days to attain tillering, heading, flowering and maturity demonstrated higher positive correlation coefficients, ranging from 0.73 to 0.99, with their corresponding GDD requirements, and thus indicating the dependence of phasic thermal time requirements on phenophase durations. Requirement of higher thermal time in early sown rice crop for completion of heading corroborates the previous work of Singh *et al*. (2012) in transplanted rice. The June sown crop in present study availed more time of hot summer months than did July sown crop and hence accumulated more thermal time.

Crop-weather relations

The performance of a crop is dependent mainly on the growing season weather conditions and the genetic constitution of crop species. Hence, identification of critical weather variables and their quantification at different growth phases is prerequisite for successful crop production in a region. Correlation coefficients (Table 2) between weather parameters at different phenophases of rice and grain yield indicated that there was a significant positive correlation of T_{max} with grain yield during flowering, however, a significant negative correlation during heading phase. Except at tillering and flowering phases, T_{min} showed negative correlation with grain yield. The BSH exhibited significant positive correlation with grain yield establishing thereby that light plays an important role in the growth and yield of rice during flowering phase. The significant positive association of T_{mean} at milking, dough and maturity phases with grain yield was observed; demonstrating thereby that higher T_{mean} led to enhanced grain yield.

The relationships of mean BSH during flowering stage and T_{max} during heading and flowering stages with grain yield of *kharif* rice have been presented in Table 3. The relationship between grain yield and BSH indicated that mean BSH during flowering stage showed positive linear relationship with grain yield, ascribing to increasing grain yield with lengthening BSH. The coefficient of determination (R^2) of regression equation (Table 3) involving grain yield and BSH explained 64 per cent of total variability in grain yield. The rate of increase of grain yield per 1 hour rise in sun shine during flowering phase was 2.7 q ha^{-1}. Yamagata (1958) reported that the number of tillers and ears (panicles) increased with the intensity and quantity of light. In the present study, BSH during flowering to maturity phases demonstrated positive correlation with grain yield (Table 2), leading to the fact that higher values of BSH prevailing during anthesis to maturity augmented the grain yield and its attributes. De Datta and Zarate (1970) observed significant positive correlation between solar radiation during panicle initiation to crop maturity and grain yield of rice. Analyzing the data recorded at Kolaba district of Maharashtra, Sreenivasan (1979) observed that more sun shine at the time of panicle emergence to fertilization leads to greater yield. It was noted that grain yield was higher at mean BSH between 7 to 8 hours during flowering stage, while yield decreased with BSH of less than 7 hours during this growth stage.

CONCLUSIONS

Crop weather relationship studies brought out several critical information, which could be useful in achieving attainable yield of *kharif* rice in the state of Bihar. Higher grain yield was observed at T_{max} between 32.2 and 32.6 ^{0}C during heading phase, while grain yield reduced appreciably when $T_{max} > 33$ ^{0}C was recorded during this phase. Daily bright sunshine hour (BSH) of 7 to 8 hours was found to enhance the grain yield, while the yield decreased at BSH of less than 7 hours during flowering stage. Weather during flowering phase of the crop played most important role by exercising its impact on grain yield.

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Weather based relationship of adult moth catches of pink bollworm (*P. gossypiella*) and leaf eating caterpillar (*S. litura*) in cotton growing area of Anand, Gujarat

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ABSTRACT

The data pertaining to adult moth catches of pink bollworm (*Pectinophora gossypiella*) and leaf eating caterpillar (*Spodoptera litura*) recorded for nine years (2006-2014) using the light trap installed at College Agronomy Farm, Anand were analysed in terms of weather parameters obtained from the agrometeorological observatory, Anand. Both the insects were found to be active throughout the year, however their populations were minimum during April to September. The correlation analysis indicated that the most of the weather parameters had negative and significant association except sunshine hours, which has significant positive correlation. The stepwise regression analysis revealed that wind speed and morning vapour pressure could explain 87 per cent variation in pink bollworm, while wind speed and afternoon vapour pressure could explain 65 per cent variation in leaf eating caterpillar.

Key words: *Pectinophora gossypiella, Spodoptera litura,* adult moth catches, light trap, cotton, weather parameters.

Cotton, being a major agricultural cash crop in India, has a major impact on overall Indian agriculture sector. *P. gossypiella* commonly known as pink bollworm damages squares and bolls of cotton. Larvae burrow into bolls through the lint and feed on seeds. As the larva burrows within a boll, lint is cut and stained, resulting in severe quality loss. Under the dry conditions, yield and quality losses are directly related to the percentage of bolls infested and the numbers of larvae per boll. If application of remedial measures does not apply at proper time, it will result in reducing the yield at large extend. *S. litura* commonly known as leaf eating caterpillar is also polyphagous in habit, feeds on variety of host plants and survives throughout the year in a given agro-eco system (Gedia *et al.*, 2008). For management of these pests, one must have prior knowledge of the time and severity of the outbreak of pests. Climatic parameters have direct relationship with the development and population of *S. litura* (Pandey *et al.*, 2015). Forewarning system can help in this direction. The study was carried with objective to (i) monitoring the insect through light trap (ii) the relationship among trap catches and weather parameters to build up regression model to predict the pest abundance.

MATERIALS AND METHODS

The present study was carried out for the occurrence and activity of different pests in cotton crop and their relationship with weather parameters. The light trap was installed in the cotton growing area at college farm, B. A. College of Agriculture, AAU, Anand. The light trap was operated throughout the year during 2006 to 2014. The adult moth catches were collected every week and brought to the laboratory for identification. Identified insects were grouped into their order and species based on their morphological characters. Nine years catches data were averaged out over standard meteorological weeks (SMW) for both the pests. These data were subjected to correlation and regression analysis. The multiple regression equation were fitted by step-wise regression technique using all the weather parameters and both the pests to develop forewarning models.

RESULTS AND DISCUSSION

Population dynamics of P. gossypiella and S. litura

The yearly variation of adult moth catches of pink bollworm (*P. gossypiella)* and leaf eating caterpillar (*S. litura*) are given in Fig. 1. It is seen that pink bollworm catches were more during 2006 to 2010, whereas leaf eating caterpillar were observed in all the years. The annual variation in these insects/pests are depicted in Fig. 2. The

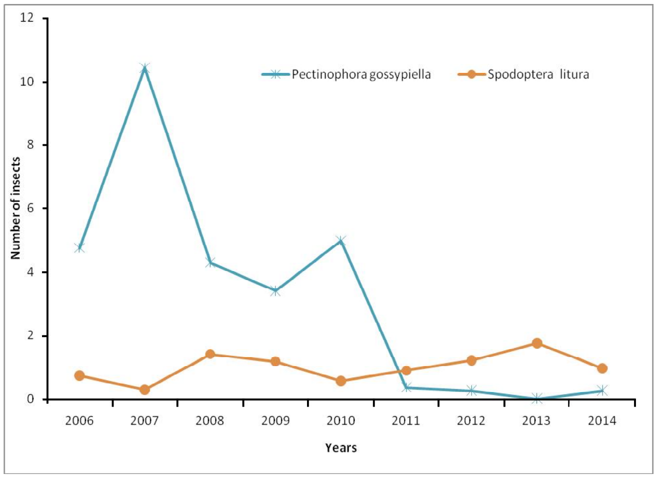

Fig. 1: Number of catches of different insects during 2006-2014

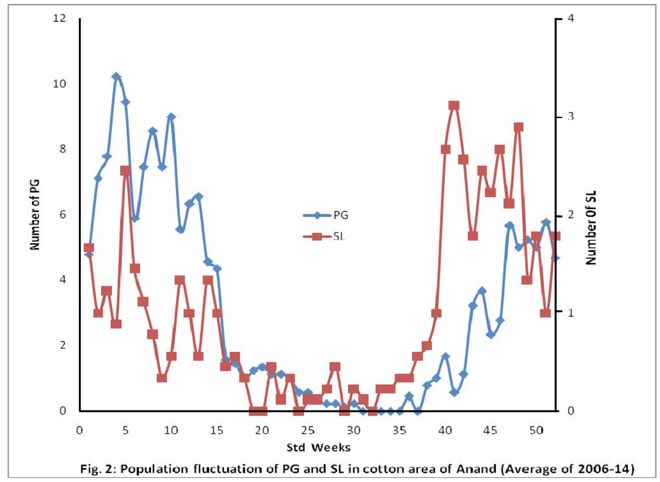

Fig. 2: Population fluctuation of PG and SL in cotton area of Anand (Average of 2006-14)

Table 2: Correlation coefficients between numbers of catches of ***P. gossypiella*** and ***S. litura*** with weather parameters

Parameters	*P. gossypiella*	*S. litura*
Maximum temperature (Tmax)	-0.323*	-0.190^{NS}
Maximum temperature (Tmin)	-0.884**	-0.533**
Morning relative humidity (RH-1)	-0.295*	0.192^{NS}
Afternoon relative humidity (RH-2)	-0.633**	-0.325*
Wind speed (WS)	-0.683**	-0.776**
Evaporation (EP)	-0.15^{NS}	-0.346*
Rain fall (RF)	-0.574**	-0.471**
Sunshine humidity (BSS)	0.561**	0.292*
Morning vapour pressure (VP1)	-0.925**	-0.518**
Aftrenoon vapour pressure (VP2)	-0.863**	-0.467**

*, ** significant at 0.05 and 0.01 level of probability, respectively. NS –non significant

incidence of *P. gossypiella* started from 37th SMW (September), gradually increased and reached at peak during 5th SMW (February) and pest remained active till 15th SMW(April). Thereafter, pest population suddenly decreased and no pest activity was observed during 31st to 36th SMW (Fig. 2).

Spodoptera litura incidence was very low during the period of 19th SMW to 32nd SMW (Fig.2). Population built up from 33rd SMW and it reached at peak during 41st SMW. Rameshbabu *et al*. (2015) have reported that male moth populations of *S. litura* were active from August to mid-October and decreased sharply in late October. Peak period of *S. litura* male moths was observed during the rainy season (July- October) in groundnut and soybean crop area (Singh and Sachan, 1993).

Relationship with weather parameters

The correlation coefficient between insects population and weather parameters are presented in Table 2. The results indicated that all the weather parameters played an important role in development of both the insects. Most of the weather parameters significantly but negatively correlated with the population of both the insects. *Spodoptera litura* showed positive significant correlation with BSS and significant negative correlation with minimum temperature, morning humidity, wind speed and vapour pressure. Prasad *et al*. (2008) observed that all the weather parameters except morning relative humidity had highly significant negative influence on the pheromone trap catch of tobacco caterpillar.

Development of forewarning model

The stadard week wise data of average catches of both the insects and weather parameters were subjected to regression analysis by using stepwise regression technique for selection of varibles to develop forewaring model. These are;

P. gossypiella = 11.860+0.285WS*-0.567VP1** (R^2=0.87)

S. litura = 2.071-0.425WS**+0.057VP2* (R^2=0.65)

Among all the variables put in the regression equation only two variable viz wind speed and vapour pressure were found to contribute significantly in explaining the variation the insects population. The model for *P. gossypiella* explained 87per cent of the total variation while that for *S. litura* explained 65 per cent of the variation in population. The models can be used for predicting their population.

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Impact of weather parameters on population dynamics of oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) under south Gujarat mango ecosystem

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ABSTRACT

The field experiment was conducted during 2013-16 at Navsari Agricultural University, Paria, Gujarat to study the role of weather parameters on population dynamics of oriental fruit fly, *Bactrocera dorsalis* on mango, *Mangifera indica* L. Fruit flies were recorded throughout the investigation period, wherein maximum catches were observed during April - July which coincided with fruiting and harvesting stages of the crop. Weather parameters *viz.,* minimum temperature, evening relative humidity, rainfall and wind velocity were found to be important predictors of fruit fly catches, while maximum temperature and morning relative humidity failed to establish significant correlation with the catches. The optimized model developed using rainfall and wind velocity predicted fruit fly catches based on R^2 value to the tune of 78 per cent. This forewarning model may help mango farmers to take advance decision for minimizing the quantitative and qualitative crop losses caused by fruit flies of the region.

Key words: Fruit fly, correlation, population dynamics, prediction, regression, weather parameters.

Mango, *Mangifera indica* L. (Anacardiaceae) is one of the appetizing fruit crops of tropical as well as subtropical regions of India and is known as "king of fruits" due to its delicious taste, attractive color, savoring flavour and high nutritive value (Lakashminarayana, 1980). More than 300 insect-pest species have been recorded to attack mango in different parts of the world (Pena *et al.,* 1998). Of these, 188 species have been reported in India (Tandon and Verghese, 1985). Among all mango pests, fruit flies are recorded as major pest of mango and three species *viz*; *Bactrocera dorsalis* (Hendel), *B. zonata* (Saunders) and *B. correcta* (Bezzi) are considered as major species (Choudhary *et al.,* 2012 and Verghese *et al.,* 2006). *B. dorsalis* is reported as predominating species and its population is found to be recorded throughout the year in mango ecosystem of south Gujarat (Patel *et al.,* 2013). During ripening stage of mango fruits, female fruit fly lays eggs in the fruit skin with the help of ovipositor and after hatching, the maggots start feeding inside the fruit pulp and causes internal discoloration, off flavors, pulp rotting and fruit drop on the ground and pupates in the soil (Sarwar *et al.,* 2014). Patel *et al.* (2013) observed that fruit flies cause up to 40 per cent yield loss in heavy rainfall zone of south Gujarat.

The aim of present study was to relate the population dynamics of fruit fly with weather parameters under southern agro-climatic Gujarat conditions. Some similar work has been carried out by several workers in different climatic conditions of India (Verghese *et al.,* 2006; Mishra *et al.,* 2012; Singh *et al.,* 2013; Choudhary *et al.,* 2012) but limited work has been done in south Gujarat where mango production centers (especially of Alphonso and late maturing varieties) are mainly located in costal environment. An analysis of ecological issue within southern Gujarat will provide essential information for understanding the population dynamics of fruit fly in the region and will also provide scientific data for formulating management strategies.

MATERIALS AND METHODS

The present studies were carried out in the mango orchard (cv. Alphonso) of All India Coordinated Research Project on fruits, Agriculture Experimental Station, Navsari Agricultural University, Paria (20°26'N, 72°58'E, 10 m at altitude) on 10-12 years old mango trees (planted on 10 x 10 m distance). Fruit fly population was monitored on the basis of total male fruit flies collected during standard week starting from 14^{th} SMW (2-8 April, 2013) to 13^{th} SMW (26-1 April, 2016) with the help of methyl eugenol impregnated Nauroji-Stonehouse parapheromone trap (plywood blocks $5x5x1cm^3$ impregnated in mixture of ethyl alcohol: methyl

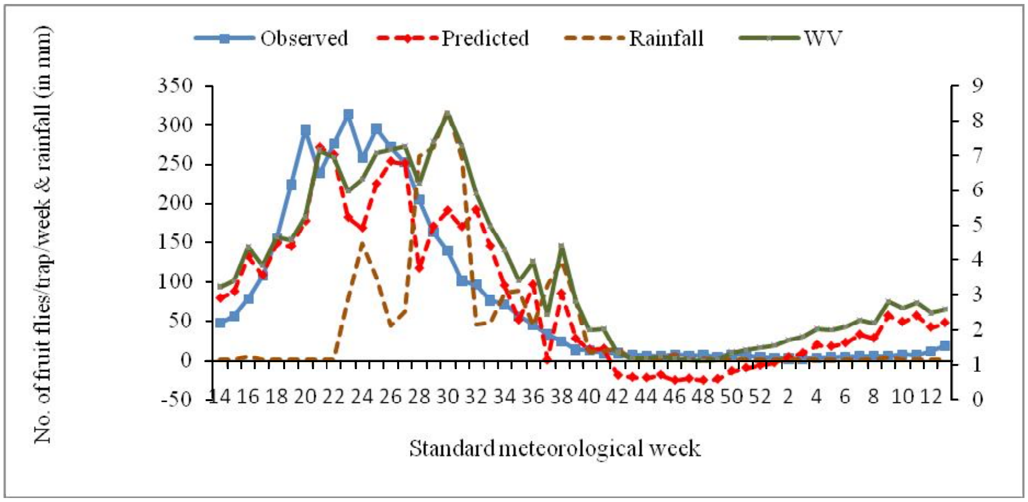

Fig.1: Standard week wise observed versus predicted fruit fly population (using optimized model)

eugenol: DDVP @ 6:4:1 v/v/v for 24 hrs) @ 1 trap per 10 plants and total ten traps were placed in one hectare mango (cv. Alphonso) plot. Traps were placed at 2-3 meters above the ground level. The Alphonso mango block was kept free from any pesticide application during the study period. Identification of fruit fly species was done using Stereomicroscope (SZ61 Magnification, 2.0x-270x) and key and species description was done as suggested by Prabhakar *et al*. (2012). The weather parameters *viz.,* maximum and minimum temperature, morning and evening relative humidity, rainfall and wind velocity were recorded from meteorological observatory of the research station. Statistical analysis of the data was carried out using IBM SPSS software.

RESULTS AND DISCUSSION

Population dynamics of fruit fly

The results of the study (Fig. 1) indicated that mean male population of fruit flies varied from 1.7 to 312.7 per trap indicating maximum population during 23rd SMW (312.7 males /trap) when the prevailing maximum and minimum temperature, morning and evening relative humidity, rainfall and wind velocity were 35.3, 25.9^{0}C, 63.6-78.4%, 76.8 mm and 5.9 kmh^{-1} followed by 25th (294.13 males /trap), and 20th SMW (292.73 males /trap), respectively which coincided with ripening cum harvesting stage of the mango fruits. Thereafter, population started declining gradually (August to March). The present findings are in agreement with Patel *et al.* (2013) who reported highest fruit fly population during 22nd SMW (28-3 June) followed by 23rd and 21st SMWs which coincided with ripening cum harvesting stage of mango fruits.

Table 1: Correlation coefficient between fruit flies complex and weather parameters under south Gujarat conditions

Abiotic parameters	Correlation coefficient Male fruit fly catches
Max. temp. (X_1)	0.050 ^{NS}
Min. temp. (X_2)	0.710**
Morning RH (X_3)	0.046^{NS}
Evening RH (X_4)	0.525**
Rainfall (X_5)	0.363**
Wind velocity (X_6)	0.850**

*Significant at 0.05 level, **Significant at 0.01 level

Effect of weather parameters on population dynamics of the fruit fly

The results revealed that total fruit fly collection exhibited significant positively correlation with minimum temperature (‘r’= 0.710), evening relative humidity (‘r’= 0.525), rainfall (‘r’= 0.363) and wind velocity (‘r’= 0.850). Whereas, maximum temperature (‘r’= 0.050) and morning relative humidity (‘r’= 0.046) indicated non-significant correlation with fruit fly catches (Table 1). So, it is concluded that with increase in minimum temperature, evening relative humidity, rainfall and wind velocity, there was corresponding increase in fruit fly catches. During this period, overall average maximum temperature ranged between 29.4 and 38.8 ºC and the minimum temperature ranged between 8.8 and 26.2 ºC. Morning relative humidity ranged between 69-95 per cent and evening relative humidity ranged between 31-87 per cent. Wind velocity varied between 1.1 to 7.3 kmh^{-1} and average rainfall was 2191 mm. The results of the present investigation are in agreement with findings of Verghese *et al.* (2006) who reported that wind speed and minimum temperature showed significant and positive correlation with B. dorsalis. Sahoo *et al.* (2016) reported that abiotic factors *viz.,* day temperature, night temperature, heat sum significantly positive correlation with mango fruit fly population and direct effect on the growth and development.

Statistical model developed using step wise regression analysis having rainfall (X_5) and wind speed (X_6) parameters could explain variability in the fruit fly catches up to 78 per cent.

$$Y=-79.64 + (-0.41) X_5 + (49.16) X_6 \qquad R^2=0.78$$

This models was considered as optimized model. A graphical representation of observed and predicated fruit flies catches (based on optimized model) is depicted in Fig. 1. Weather based predication model for guava fruit fly was developed by Sharma *et al.* (2015) who reported the regressing peaks of fruit fly trap catches on mean values of different weather parameters of April-March weeks (R^2= 0.80). This prediction model is highly useful for estimating fruit fly population one week in advance and saves valuable time and possible crop loss.

CONCLUSIONS

The present study clearly indicated that wind velocity, minimum temperature, evening relative humidity and rainfall significantly showed positive correlation with male fruit fly population or the catches. Based on optimized model, wind velocity with combination of rainfall played a significant role in inducing significant variation in male fruit fly population in methyl eugenol traps during fruiting to harvesting stage of mango under south Gujarat conditions.

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Seasonal dynamics of insect pests of sugar beet under sub-tropical conditions

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ABSTRACT

The present study was conducted for three years (2012-13 to 2014-15) on sugar beet crop at PAU, Ludhiana to establish the relationship between weather parameters and insect pests infesting sugar beet crop. The observations on the incidence of insect pests recorded at weekly intervals were analyzed to correlate the effects of the abiotic factors on population of insect pests. Aphid, *Myzus persicae* Sulzer population showed negative correlation with maximum and minimum temperature and positive correlation with relative humidity. *Spodoptera litura* Fabricius and *Helicoverpa armigera* (Hubner) showed positive correlation with maximum and minimum temperature and negative with relative humidity. Regression analysis was also worked out between population of these insect pests infesting sugar beet.

Key words: Insect pests, population dynamics, sugar beet, climatic factors

Weather affects the distribution and abundance of any species at both individual and population level affecting the insect migration, outbreaks through affecting physiology, behavior and population densities (Parmesan, 2007). Moreover, response of organisms to climatic variation is species specific occurring at different rates in each species thus, resulting in an altered community structure (Sharma *et al.,* 2014). It has also been reported that many biological processes undergo sudden shifts at particular threshold values of specific months might be more important in regulating insect population as compared to annual mean temperature (Guldberg, 2001). Hence, understanding the complex interaction between insect pests and weather parameters would help in developing efficient and timely pest control strategies.

Sugar beet, *Beta vulgaris* Linnaeus is an important agricultural asset being a pure source of sucrose and its cultivation is economical than sugarcane with 30 per cent more sugar harvested in a short duration thus, offering an excellent opportunity to increase sugar productivity. Sugar beet is primarily a crop of the temperate region and contributes about 22-28 per cent of the world sugar production (Solomon, 2013), but advances in genetics and agro-technology have extended its scope to the sub-tropics where it can be cultivated during winter season.

In India, defoliating insects *viz* .beet armyworm (*Spodoptera litura* Fabricius), hairy caterpillar (*Diacrisia obliqua* Walker), semilooper (*Plusia orichalcea* Fabricius), cutworm (*Agrotis ypsilon* Rott.) cause appreciable damage to sugar beet at different growth stages in India (Patil *et al.,* 2007). Manoharan *et al.* (2010) reported *S. litura* as the predominant pest on sugar beet The gram pod borer, *Helicoverpa armigera* (Hubner) is a polyphagous pest of economic importance on many agricultural and horticultural crops including 180 cultivated and wild plant species (Venette *et al.,* 2003). Sugar beet could be integrated in present cultivation schedule to obtain higher sugar productivity and for this goal, it is imperative to study the population fluctuations of insect pests on sugar beet in relation to weather parameters that determine the activity and abundance.

MATERIALS AND METHODS

The studies were conducted on sugar beet crop sown during October for three consecutive years 2012-13 to 2014-15 at Agronomy Research Farm, Punjab Agricultural University, Ludhiana. The crop was raised without any insecticidal application so as to estimate the natural population of insect pests infesting this crop. The data pertaining to insect pests was recorded at weekly intervals initiating on one month old crop till harvest, in accordance with standard meteorological week (SMW). For calculating the weekly mean incidence, the observations on the incidence of insect pests were taken from selected plots from an area

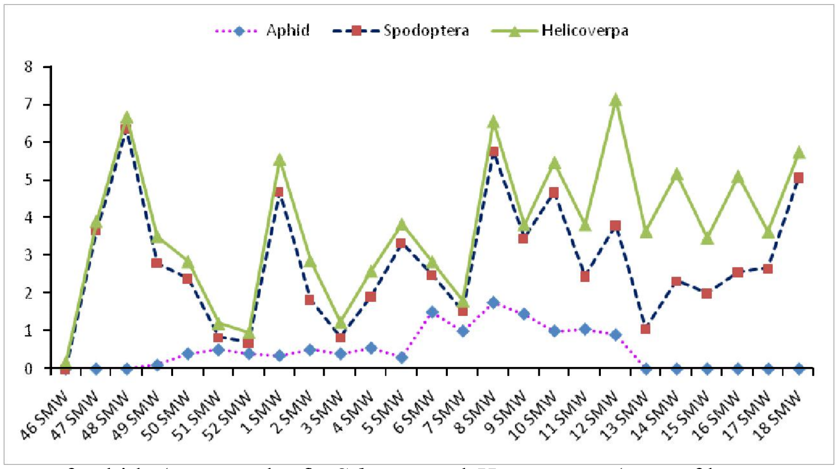

Fig 1: Seasonal abundance of aphids (nos. per leaf), *S.litura* and *H.armigera* (nos. of larvae per plant) on sugar beet

Table 1: Correlation coefficient of insect pests on sugarbeet with weather parameters

Weather Parameter	Correlation coefficient (r)		
	M. persicae	*S. litura*	*H. armigera*
Max temp (°C)	-0.398*	0.609**	0.478**
Min temp (°C)	-0.284	0.718**	0.599**
RH (%)	0.586**	-0.511**	-0.325
Rainfall (mm)	0.482**	0.042	-0.036

* Significant at p=0.05 level

** Significant at p=0.01 level

of 500 sq. m with five replications. The number of larvae of *S. litura* and *H. armigera* was taken from ten randomly selected plants starting from 49th SMW of each year. The aphid counts were taken from upper and middle three leaves of ten randomly selected plants for calculation of weekly means starting from the 49th SMW. The data on maximum and minimum temperature, rainfall and relative humidity (RH) during 2012-13 to 2014-15 was obtained from School of Climate Change and Agricultural Meteorology, PAU, Ludhiana during the months under study. Correlation and Regression equations were calculated to estimate the effects of these abiotic factors on population counts of insect pests.

RESULTS AND DISCUSSION

Population dynamics of insect pests

Three years (2012-13 to 2014-15) mean data of aphids *(M. persicae)*, *S.litura* and *H. armigera* is presented in Fig. 1. The incidence of insect pests on sugar beet was observed in 46th SMW and continued till the 18th SMW of next year in all the years under present study. Aphids were found to appear in 49th SMW and attained peak values (>1.00) during 6-9th SMW. Thereafter, it decreased and disappeared after 13th SMW. The larvae population of *S.litura* and *H. agrmigera* were found to vary during the season, however, both the insect/pests showed similar variation pattern. The larvae count of *H. armigera* were slightly higher than that of *S.litura*.(Fig. 1.)

Correlation with weather parameters

Correlation was worked out between population of these insect pests infesting sugar beet and meteorological parameters to study the effect of abiotic factors on pest population. It was observed that *M. persicae* population showed negative correlation with maximum and minimum temperatures and highly significant positive correlations with relative humidity and rainfall. *H. armigera* showed highly significant positive correlations with maximum and minimum temperatures and negative but non-significant correlations with relative humidity and rainfall. *S. litura* showed significant positive correlations with maximum and minimum temperatures and significant negative correlation with relative humidity.

On the basis of highest correlations obtained with different weather parameters, simple regression equations were developed for each pest. The best regression equation for *M. persicae is* $y= 14.08x + 63.12$ (R^2=0.343) which explains 34.3 % variation in its population. Maximum temperature was found to explain maximum variation in

S.litura (y= -3.245x + 77.37) with R^2=0.515 and for *H. armigera* the model equation y= 3.084x + 7.996 (R^2=0.359) explains 35.9 per cent variation. These models can be used for predicting the insect/pest population on sugar best at Ludhiana.

Saxena *et al.,* (2012) observed that population build up of *Lipaphis erysimi* in mustard was negatively correlated with maximum and minimum temperature. In yet another study conducted by Sharma *et al.,* (2013), it was observed that aphid population on tomato was positively but non-significantly correlated with the maximum, minimum temperature and negative non-significantly correlated with relative humidity (maximum and minimum) and rainfall. Studies by Thakur and Rawat (2014) reported a positive correlation between the insect pest trap catches of *Helicoverpa* spp. and *Spodoptera* spp. and abiotic factors viz. maximum temperature and minimum temperature, relative humidity and rainfall. The results of present study are also in coherence with the findings of Singh *et al.* (2011) who reported that rainfall and relative humidity were negatively correlated with the pest activity, whereas the maximum and minimum temperature, were positively correlated with relative humidity.

CONCLUSION

From the present studies, it could also be concluded that aphid, *M. persicae* population on sugar beet showed negative correlation with maximum and minimum temperature and positive correlation with relative humidity. *S. litura* and *H. armigera* showed positive correlation with maximum and minimum temperatures and negative correlation with relative humidity.

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Progression of powdery mildew on different varieties of wheat and triticale in relation to environmental conditions

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ABSTRACT

Six varieties of wheat and triticale (DDK1029, TL2934, PBW174, DPW 621-50, PBW343 and PBW590) were sown in the field of Indian Institute of Wheat and Barley Research, Karnal, Haryana (IIWBR) and Regional Research Station, Dhaulakuan under Himachal Pradesh Krishi Vishvavidyalaya, H.P during seasons 2012-13 and 2013-14 to study the role of environmental factors on the development of powdery mildew of wheat (*Erysiphe graminis* f.sp. *tritici*). The disease development was positively correlated with temperatures and negatively correlated with evening relative humidity and rainfall under field conditions. Best fit regression model was developed with maximum temperature, evening relative humidity and rainfall across the varieties and locations which explains 64% variation in powdery mildew disease.

Key words: *Wheat, Triticale, Erysiphe graminis f.sp. tritici, epidemiology, weather parameter*

Powdery mildew is one of the widely destructive plant disease in the world. Powdery mildew is caused by biotrophic parasitic fungus *Erysiphe graminis* f.sp. *tritici* Em. Marchal (syn: *Blumeria graminis*), with well developed haustoria that permit it to feed on the cell contents without extensive injury to the supporting tissue. Powdery mildew was endemic in foot hills and valley areas of northen and southern hills in India. However due to changing cropping practices, it has become an important disease in warmer regions and plains also (Bahadur *et al.*, 1996). It is observed to be severe in northen India especially in Punjab on widely grown wheat varieties PBW 343, WH 542, UP 2338 etc. Rani and Munshi (2004) reported that disease index was positively and significantly correlated with temperature, whereas humidity was not a pre-requisite for disease development. In view of the enormous losses caused by this disease, different environmental factors affecting epidemic development of the disease under field conditions were studied.

MATERIALS AND METHODS

Wheat and triticale varieties DDK1029 and TL2934 powdery mildew resistant, PBW174 and DPW 621-50 moderately resistant, PBW343 and PBW590 susceptible were sown in the field of Indian Institute of Wheat and Barley Research, Karnal, Haryana (IIWBR) and Regional Research Station, Dhaulakuan under Himachal Pradesh Krishi Vishvavidyalaya, H.P, with three replications. The observations on disease intensity for each variety, ten leaves were marked randomly, and powdery mildew growth was measured regularly till the senescence or drying of leaves on different varieties at 5 days interval. The disease reaction was recorded based on scale given by Saari and Prescott (1975). The data on environmental variables viz. maximum and minimum temperature, morning and evening relative humidity, rainfall and sunshine hours were obtained from meteorology laboratories of IIWBR, Karnal and Regional Research Station Dhaulakuan, Himachal Pradesh. Per cent disease index (PDI) was calculated by formula given by Wilcoxson *et al.* (1975):

$$PDI = \frac{\text{Total sum of numeral rating}}{\text{Total number of plants observed X Maximum disease grade}} X\ 100$$

Correlation was carried out between weather parameters and percent disease intensity by pooling the data of all the varieties and both locations during the season 2012-13. Multiple regression equation was developed for estimation disease intensity based on significant weather parameters of the year 2012-13 using stepwise regression analysis. This multiple regression equation was used for prediction of disease intensity using weather as input parameters at both the locations during the season 2013-14. Goodness of fit between actual and estimated/predicted percent disease index were tested using Chi square test.

RESULTS AND DISCUSSION

The powdery mildew (*Erysiphe graminis* f.sp. *tritici*) progress was measured on different wheat varieties in terms

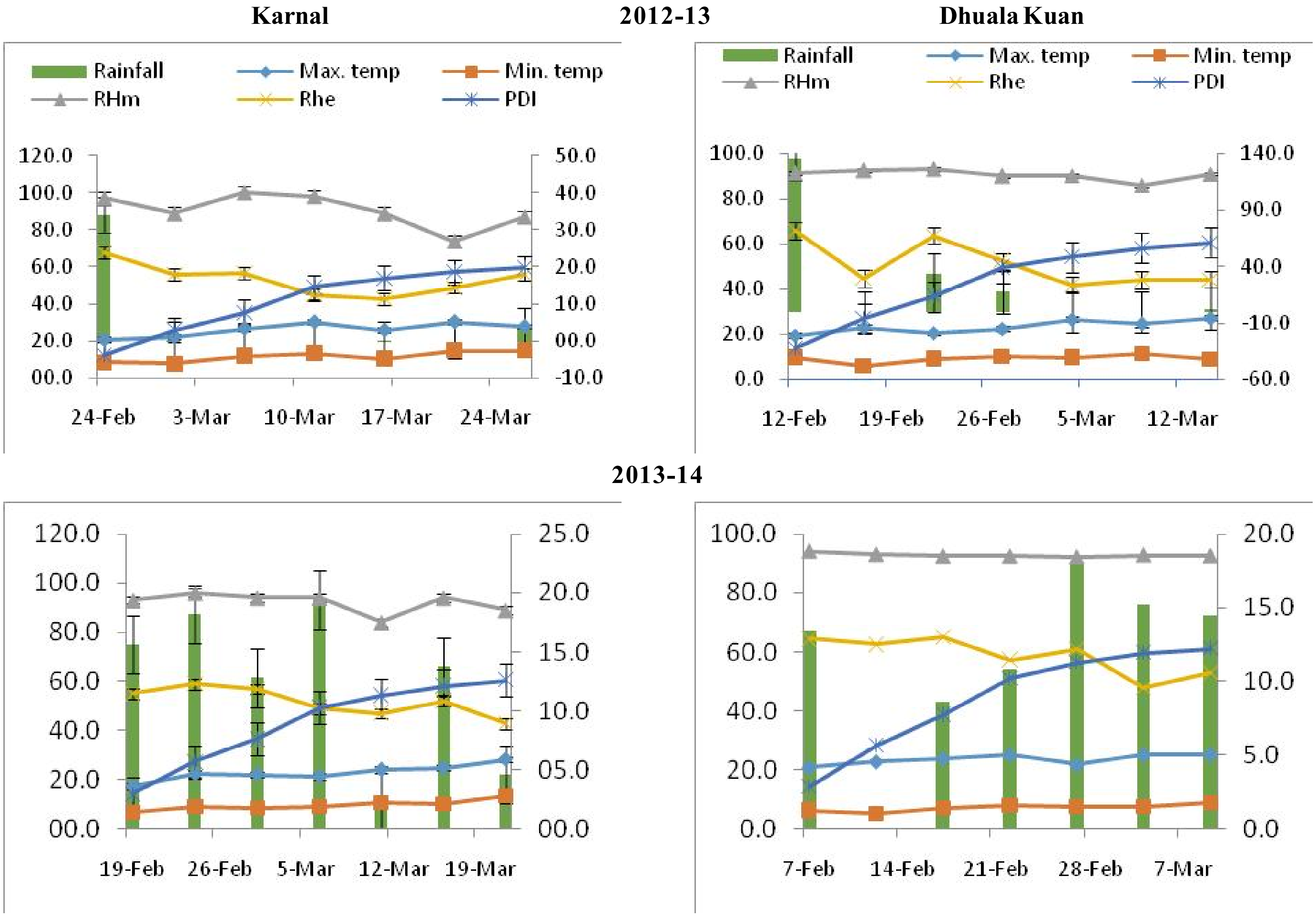

Fig 1: Development of powdery mildew (*Erisiphe gramminis* f.sp. *tritici*) on wheat cultivar PBW 343 at Karnal and Dhaulakuan during 2012-13 and 2013-14

of per cent disease index in relation with prevailing weather conditions. Powdery mildew was observed on all the variety in third week of February except cultivar DDK 1029 and TL 2934, which were infected in last week of February in Karnal. The temporal variation in per cent disease index (PDI) of susceptible variety (PBW 343) is depicted in Fig. 1 along with weather parameters of both seasons and locations. Powdery mildew infected wheat crop later during 1st season as compared to second season. Similarly incidence on wheat crop was earlier at Dhaula Kuan during second season. The disease incidence was about 12 days earlier in wheat crop grown at Dhaula Kuan as compared to wheat at Karnal station during both crop seasons. Initially PDI was around 12.8 per cent and increased with linear rate up to 1st week (2012-13) and 2nd week (2013-14) of March thereafter comparatively at slow rate and attained maxima in last fortnight of March at Karnal. In March, rise in temperature did not favored development of the pathogen might be due to lesser availability of green tissue towards maturity. According to Mzhavanadze (1975) development of powdery mildew resistance was favoured by relatively cold weather (air temperature of 14.5 to 18.2°C) and relative humidity of 50-80 per cent. Boskovic (1988) found that severe infection of powdery mildew occurred at 12-16°C.

The coefficients of correlation between disease index and weather parameters (Table 1) shows that coefficients were significant with maximum temperature (Tmax) (r=0.72), evening relative humidity (RHe) (r=-0.71). and rainfall (r=-0.60) negatively correlated with disease index. This indicates that the temperature, humidity and rainfall are important for powdery mildew disease progression. Kumar and Singh (1987) found that conidia of wheat powdery mildew germinated at temperatures between 5-30°C with an optimum at 20°C in dark and at 100 per cent relative humidity. Pandey *et al.,* (2004) reported different climatic requirement of powdery mildew in Ber while Kanzaria *et al.,* (2013) developed prediction model for powdery mildew in mustard in Saurashtra, Gujarat.

Multiple regression equation was developed for

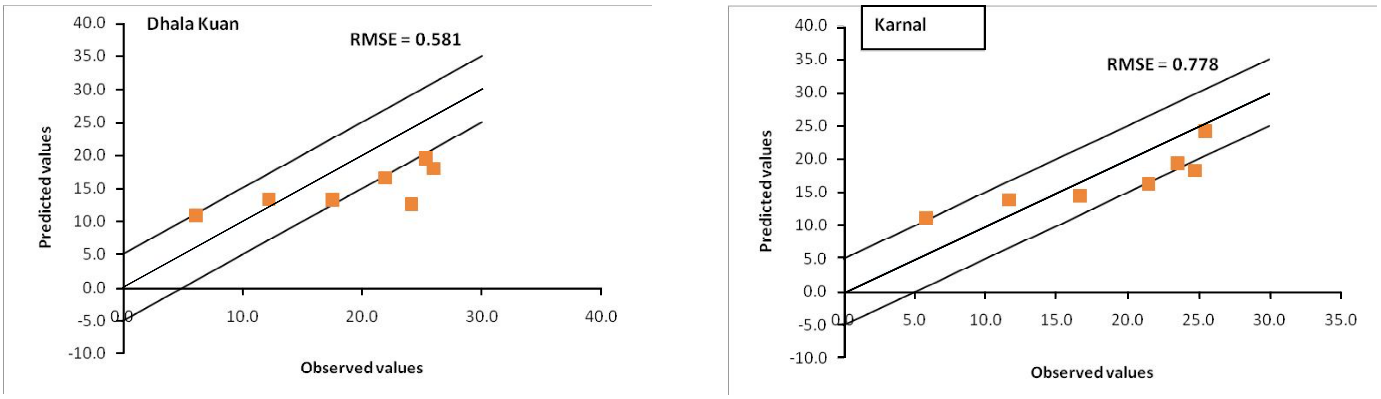

Fig 2: Comparison between observed and predicted values of powdery mildew disease on at Karnal and Dhuala Kuan

Table1: Correlation between powdery mildew disease progression on wheat and weather parameters (pooled data for all variety and locations)

Weather Parameters	Correlation Coefficient (r)
Maximum temperature	0.72*
Minimum temperature	0.56
Morning relative humidity	-0.44
Afternoon relative humidity	-0.71*
Rainfall	-0.60*

prediction of mildew disease index in wheat across the varieties and locations for the year 2012-13.

$$PDI = 0.838 \times Tmax - 0.321 \times RHe - 0.017 \times RF + 14.3$$
$$(1.56) \quad (1.47) \quad (0.32) \quad (0.69)$$
$$R^2 = 0.64^*$$

Maximum temperature, evening relative humidity and rainfall collectively explained the variability in disease progression up to 64 per cent. The overall R^2 value indicates that unaccounted variability of 36 per cent in disease progression was due to some unknown factors involved in the powdery mildew disease development in wheat. The present results are in accordance with the studies done by Podhradszky and Csuti (1962), that mild temperature were also reported to be favourable for disease development.

The best fit model based on three weather parameters was used for prediction of powdery mildew disease progression for the year 2013-14 at both locations. The predicted disease intensity values were compared with the observed values in wheat grown at Karnal and Dhaula Kuan stations during 2013-14 and their progression is depicted in Fig. 2. RMSE value indicates that predicted values followed observed disease intensity more closely at Dhaula Kuan as compared to Karnal.

CONCLUSION

Based on the above results it is concluded that powdery mildew disease progression was best associated with maximum temperature followed by evening relative humidity. Temperature increment favoured and relative humidity increment disfavoured the powdery mildew disease progression.

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Short Comminucation

Development of the agro-climatic grape yield model for the Nashik district, India

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Grape is an important fruit crop due to its nutrient value. It helps the socio-economic growth of Indian farmers by exporting it to European and Arabian countries. Nashik district of Maharashtra is famous for growing horticultural crops (grape, pomegranate, onion etc.). About 40% agricultural land of the Nashik district is under the cultivation of the grape crop. Due to fluctuation in climatic parameters the yield of grapes has been adversely affected. The quantification of climatic parameters in the terms of grape yield will be helpful in developing model for prediction the grape yield. So it is needed to develop agro-climatic model for grape crop to forecast the yield to help planners/ farm managers to take appropriate measures for management of harvest (Kumar *et.al.,* 2014). This study aims to find out the relationship between the agro-climatic parameters and grape yield of Nashik district.

The climatic parameters such as temperature, relative humidity, sunshine hours, and precipitation were collected for the period of 1991-2014 from the Indian Metrological Department (IMD), Pune. The grape yield data of corresponding periods were collected from National Horticulture Board (NHB) Nasik. Fertilizer consumption data was collected from agriculture department of Nashik division, Maharashtra. Fertilizers consumptions has been considered for the month of September to March, because mostly fertilisers are being used after fruit pruning (Adsule,2013).

Selection of variables and statistical analysis

For the present model due care is taken to cover up maximum significant parameters. The model represents the entire phenomenon of the crop yield is therefore functionally given as;

$$Y = f(P, T, S_h, R_h, F,) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, Y is grape yield (ton ha^{-1}), P is precipitation (mm), T is average temperature (^{0}C), S_h is sunshine (hours), and R_h is relative humidity (%).

The correlation analysis was done to find out the relationship between dependent and independent variables. If the correlation coefficient factor is greater than ± 0.3 then it would be considered for further analysis. The correlation analysis is given in the Table 1. Accordingly it shows correlation between i) yield and temperature (June and September), ii) yield and precipitation (August, September and November), iii) yield and relative humidity (August, September and November), iv) yield and sunshine hours (April, October, November, and January), v) yield and fertilisers use. Therefore these variables, which are highly correlated with the grape yield were considered for further analysis.

The variables considered for the model development were statistically checked for their significance (Popova and Kercheva, 2005). The P-test has been carried out to check the significance of parameters which are based on the variance factors. After the checking of significance, regression analysis was done for all the pairs of variables, to select the final form of the model. If P-value is less than 0.05, then parameters are statistically significant and only those were considered for present model. The parameters such as temperature, relative humidity and sunshine hours were not statistically significant as P-value is greater than 0.05 (Table 2). Among all other mentioned parameters precipitation of August and November, and use of fertilizers are statistically significant. Hence, the relationship between grape yield and precipitation in the month of August and November has been developed using regression analysis.

Model calibration and validation

The final form of the developed grape yield model is shown in the equation (2).

$$(Y) = 0.47 \times (42.8F - 0.019P_a - 0.21P_n - 7.026)\ldots\ldots\ldots\ldots(2)$$

For the calibration of grape yield model, observed data set of the period from 1991 to 2006 has been used. Where; (Y) is Grape yield (ha^{-1}), F is fertilisers use (ha^{-1}). P_n is precipitation of November (mm) and P_a is precipitation of August (mm).

For the validation of developed grape yield model, independent data set from the year 2007 to 2013 was considered and was is good agreement with the value of coefficient of determination (R^2) of 0.92.

Table 1: Correlation analysis between monthly climatic parameters and grape yield.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Average -Temperature (t °)	0.12	-0.07	0.30	0.18	0.20	0.30	0.12	-0.13	0.13	-0.01	-0.05	0.09
Precipitation (P)	-0.09	0.04	-0.20	-0.11	-0.30	0.32	0.12	-0.79	-0.22	0.14	-0.05	0.15
R. Humidity (Rh)	-0.18	-0.14	0.09	-0.06	-0.40	-0.34	0.05	-0.35	-0.22	0.01	0.06	-0.10
Sunshine hours (Sh)	0.53	-0.29	0.24	0.23	0.11	-0.07	0.45	-0.54	0.09	0.39	-0.02	0.09
fertilizers use	-	-	-	-	-	-	0.70	-	-	-	-	-

Table 2: The analysis of variance (P-value)

Parameters	Month	Coefficients	Standard Error	P-value
Average Temp (°C)	Jun	-0.047	1.575	0.976
	Sep	1.383	1.442	0.349
Precipitation	Aug	-0.022	0.009	0.023
	Sep	0.009	0.011	0.438
	Nov	-0.197	0.036	0.000
Relative Humidity	May	-1.318	2.169	0.586
	Jun	-0.517	1.106	0.672
	Aug	1.981	4.231	0.672
Sunshine hour	Apr	-0.632	1.236	0.631
	May	-0.025	0.692	0.973
	Jun	0.482	0.841	0.591
	Aug	-0.102	0.405	0.811
	Nov	-1.247	0.721	0.144
	Dec	-0.098	1.037	0.928
Fertilisers	F	39.910	3.909	0.000

To check the statistical fitness of developed model (Eq^n.2) various statistical tests such as discrepancy ratio (r), standard deviation of r, mean percentage error (MPE) and standard deviation of MPE are considered (Bharadiy and Manekar, 2015). The discrepancy ratio (r) is found 0.99, standard deviation (SD) of the discrepancy ratio (r) is found 0.20, whereas mean percentage error (MPE) is -0.00006, and standard deviation of MPE is found 0.20.

Further, the scatter plot of observed yield Vs simulated yield is shown in Fig. 1. The variation of the model reflects the actual yield of the scatter data points are within ± 10% bandwidth and 73% of results are found within this bandwidth.

Based on the present study, it is concluded that, the developed agro climatic grape yield model (Eq.2) can be used for the estimation of grape yield. This is also useful to determine the grape water requirement and irrigation scheduling based on the estimated grape yield model. The developed model can be used as the decision supporting tool for generating grape yield scenarios using future model inputs.

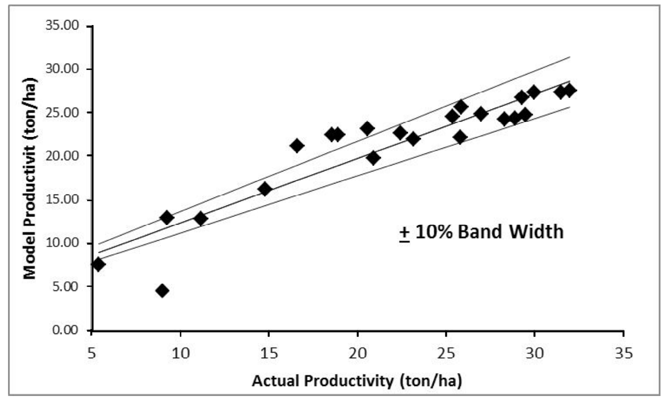

Fig. 1: The scatter plot of model and actual yield data points with ±10 % band width

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Short Comminucation

Comparison of different methods for evaluating potential evapotranspiration in Chhattisgarh

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Evapotranspiration plays major role in global water balance and significantly influences the global energy balance as well. Hence, the quantification of evapotranspiration is necessary for water resources management, irrigation scheduling and environmental assessment. Potential evapo-transpiration (PET) is defined as the amount of water that can potentially evaporate and transpire from a vegetative surface with no restrictions other than the atmospheric demand (Lu *et al.*, 2005). PET provides a good representation of the maximum possible water loss to the atmosphere. Knowledge of PET rates is essential for a variety of applications, including hydrological modeling, irrigation planning, geo-botanical studies and estimation of sensitive-to-climatic change aridity indices. Penman's combination equation is generally accepted as an appropriate method for estimating potential evapotranspiration. However, as all the climatic data required to calculate Penman's potential evapotranspiration are seldom available, potential evapotranspiration is more commonly approximated as a factor times standard evaporation pan reading. Doorenbos and Pruiit (1977) and Jensen *et al* (1990) provided detailed guidelines for using the various methods for computing potential evaporation and evapotranspiration. Different scientists from India (Khandelwal *et al*, 1999; Kumar *et al*, 1986; Krishnakumar and Prasad Rao, 2006; Kingra and Hundal, 2005) have attempted to compare these methods. Their results were found to differ from place to place. Hence location specific models are to be used.

PET have been estimated by different methods like Modified Penman's method on the lines of Penman equation, Hargreaves method, Turc method, Thornthwaite Method, Blaney- Criddle method, Christiansen method, FAO Penman-Monteith method, Monteith method. Daily data used for estimating and analyzing the PET using different methods of open pan evaporation and other meteorological parameters (air temperature, rainfall, humidity, vapour pressure and wind speed) were collected from the different agrometeorological observatories viz. Ambikapur, Jagdalpur, Raipur and Bilaspur which are representing different agroclimatic zones in Chhattisgarh. The period of data used for Ambikapur, Jagdalpur, Raipur and Bilaspur were 23 (1991-2014), 34 (1980-2014), 43 (1971-2014) and 31(1983-2014) years respectively. The daily value of open pan evaporation were measured by using a U.S.W.B. class A open pan evaporimeter at 0830 and 1430 hours IST in the Agrometeorological Observatory College of Agriculture, Raipur were used. In this investigation weekly and monthly PET values for four stations were computed using the PET v3 software (Bapuji Rao *et al.,* 2013). Based on daily data the weekly and monthly averages PET were worked out and the results are discussed for each station separately.

Annual estimation of PET

Annual estimation of PET computed by all the methods are higher at Raipur and lower at Jagdalpur in Hargreaves method. All the values of PET computed by different methods are over-estimated as compared to pan evaporation data. It seems from the Table 1 that the Turc method closely follows open pan evaporation values at Raipur though they are lower at Jagdalpur, Ambikapur and Bilaspur. Among the 7 methods, Modified Penman values are highest at Raipur while Hargreaves method PET values are highest at Bilaspur and Jagdalpur. Because of these higher estimates, the crop coefficient was more than 1 by all the methods of PET.

Seasonal estimation of PET

Based on the monthly PET values the total PET for *Kharif* and *Rabi* seasons were examined at different stations and shown in Table-2. The total values of PET during *Kharif* season varied from 453 mm to 891 mm. For example these values varied from 485 mm to 883 mm at Raipur. However the open pen values are lower during *Kharif* seasons at all the four stations as compared to PET calculated by different methods and hence the crop coefficients PET/E0 are greater than 1 during *Kharif* season. In the same way the PET values computed by different methods shows that the

Table 1: Annual PET values at different station using different methods

Stations	Modified Penman	Hargreaves	Turc	Thornthwaite	Blaney-Criddle	Christiansen	Open Pan	FAO Penman-Monteitn
Ambikapur	1590	1667	1371	1430	1534	1399	1235	1380
Jagdalpur	1557	1717	1298	1434	1390	1106	951	1372
Raipur	1848	1798	1421	1842	1739	1537	1260	1627
Bilaspur	1521	1735	1378	1768	1553	1301	1157	1297

Tables 2: Seasonal PET values at different station using different methods

Stations	Modified Penman	Hargreaves	Turc	Thornthwaite	Blaney-Criddle	Christiansen	Open Pan	FAO Penman-Monteitn
Kharif (June- Oct.)								
Ambikapur	639	680	557	729	532	564	487	564
Jagdalpur	591	643	499	646	452	365	313	517
Raipur	731	693	556	883	584	618	485	640
Bilaspur	611	682	555	891	539	515	453	541
Rabi (Nov-March)								
Ambikapur	518	573	499	233	556	450	420	439
Jagdalpur	567	678	518	329	566	415	373	499
Raipur	602	653	544	354	658	435	387	525
Bilaspur	521	616	512	320	583	421	389	435

Thornthwaite PET values are lowest at all the four stations and they matched closely with open pan evaporation value. While Hargreaves PET estimates are higher in rabi season at Jagdalpur and Bilaspur while Blaney-Criddle method value of PET during rabi season are highest at Jagdalpur. The lowest Thornthwaite method value of PET is at Ambikapur. Thus there is no trend of PET estimated by different methods in all the 4 stations and it suggested that local variability of meteorological conditions is important for estimation of PET at different locations. But from the analysis for different seasons it was found that Thronthwaite values are lower than any other method but at Jagdalpur Thronthwaite PET value for *Rabi* season are more close to open pan values at Jagdalpur as compared to other stations. Seasonal estimation of PET for Ambikapur indicated that the values in general are less in winter months and high during summer months. On the contrary the PET values were over-estimated during summer months. This is true in case of all the methods. In fact all the methods over-estimated PET values as compared to open pan evaporation in summer months except Turc method in May and June.

Hence, it can be concluded that on overall basis the FAO Penman -Monteith equation seems to be more appropriate in application part as this method is rationalizing the weightage factor of different meteorological parameters.

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Short Comminucation

Climatic variability and extreme weather events in Bihar

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The changes in climate, which are likely to occur during future decades, may have significant consequences (positive or negative) on the development, growth and yields of various crops (Patel *et al.,* 2008). In the climate change studies scientists have revealed statistically significant warming trends in different parts of the world (Karl *et al*. 1993; Philandras *et al*., 1999). However, decreasing trends in weather parameters have also been reported in some part of the world (Solomon *et al.,* 2007). Regardless of the definition used, the characteristics of what is called an 'extreme weather event' may vary from place to place. Extreme positive departure from normal maximum temperature results in heat wave during summer season (De *et al.* 2005). In recent years due to deterioration of the air quality in urban locations of India the deaths and discomfort from cold waves have been substantial (De and Sinha Ray, 2000). Lunagaria *et al.,* (2012 and 2015) have reported the climatic trends in extreme weather events in Gujarat. Extreme rainfall events cause damages in the form of landslides, flash floods, crop loss, etc., which further have impacts on society as well as the environment. Hence understanding the pattern and frequency of heat waves, cold waves and extreme rainfall is essential for forecasting and management of extreme climatic conditions. A proper assessment of likely incidences of such events and their trends would be helpful to the planners in their disaster mitigation and implementations. This study is aimed to characterize the long- term trend of temperature and rainfall pattern and simultaneously extreme climatic events in Bihar state and their likely impact on crops considering four stations representing different stations.

The daily data for air temperature and rainfall were collected for the period 1955-2012 for Pusa and Sabour and 1969-2012 for Purnia and Patna representing different zones. After performing the quality check the daily records were processed for seasonal and annual temperature data series computation. The seasons reported are as: *kharif* season (June-October), *rabi* season (November-March). The extreme weather events like heat wave, cold wave and extreme rainfall were calculated following Rajeevan and Yadav (2015). The Theil-Sen approach (Hirsch *et al.* 1982) provides a more robust slope estimate than the least-squares method because outliers or extreme values in the time series affect is less. The Mann-Kendall test was used, assuming the observation in time series are serially independent and there is no correlation. The test determines whether the observations in the data trend to increase or decrease with time. Frequency and trends of heat waves (moderate and severe), cold waves (moderate and severe) and extreme rainfall (75-100 mm rainfall and more than 100 mm rainfall in a day) were analysed. The significance of each trend was examined at 95 % confidence level.

Trends in heat wave

There is significant decreasing trend of moderate and total heat waves for Pusa station whereas for Purnea station, there is increasing trend in moderate and total heat waves but statistically they are non-significant. For Sabour station, there is significant decreasing trend in moderate, severe and total heat waves (Table 1). For Patna station, there is increasing trend in moderate, severe and total heat waves but are statistically non-significant.

Trends in cold wave

For all the stations, Pusa, Purnea, Sabour and Patna, there is significant decreasing trend in moderate and total cold waves but there is non-significant decreasing trend in severe cold waves for all the stations except Sabour, where it is significantly decreasing (Table 1).

Trends in extreme rainfall

There is increasing trend in frequency of extreme rainfall (75-100 mm rainfall and more than 100 mm rainfall) for Sabour station but statistically non-significant (Table 1). There is also increasing trend in frequency of 75-100 mm rainfall in a year for Pusa station but statistically non-significant. For other stations, there is non-significant

Table 1: Mann Kendall test (Kendall's tau) with Theil-Sen slope for extreme weather events.

	Kharif		Rabi		Annual	
	tau	TS slope	tau	TS slope	tau	TS slope
Heat waves	**Moderate heat waves**		**Severe heat waves**		**Total heat waves**	
Pusa	-0.228	-0.111*	-0.118	-0.004	-0.210	-0.107*
Purnia	0.103	0.010	-0.019	-0.006	0.07	0.004
Sabour	-0.338	-0.144*	-0.272	-0.060*	-0.345	-0.205*
Patna	0.055	0.052	0.058	0.055	0.037	0.106
Cold waves	**Moderate cold waves**		**Severe cold waves**		**Total cold waves**	
Pusa	-0.43	-0.058*	-0.028	-0.001	-0.39	-0.057*
Purnia	-0.495	-0.157*	-0.139	-0.007	-0.492	-0.164*
Sabour	-0.433	-0.128*	-0.232	-0.012*	-0.430	-0.141*
Patna	-0.243	-0.063*	-0.18	-0.009	-0.262	-0.072*
Extreme rainfall	**Rainfall 75-100 mm**		**-**	**-**	**Rainfall >100 mm**	
Pusa	0.066	0.008	-	-	-0.054	-0.005
Purnia	-0.063	-0.014	-	-	-0.03	-0.002
Sabour	0.101	0.017	-	-	0.092	0.009
Patna	-0.052	-0.002	-	-	-0.094	-0.012

*Significant at 5%

decreasing trend in frequency of extreme rainfall in a year.

Decreasing trend of rainfall in *rabi* season at Pusa indicates that zone I may face water scarcity problem, which need suitable cropping system in the condition of less water availability whereas all the stations except Sabour shows decreasing trend (though non-significant statistically) of annual precipitation which will impact negatively agriculture of the region by decreased length of growing period with less water availability to agriculture. Unequal distribution of precipitation may cause drought in one area and flood in another area. The precipitation decrease in most of the zones in Bihar will impact negatively on Rice-wheat cropping system, which is the major cropping system in the area. Not only decrease in rainfall but also abnormal, irregular or excessive amounts of rainfall seriously reduce the quality and quantity of the yield in rainfed *rabi* crops. Extreme rainfall damages the crops making the field flooded.

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Short Comminucation

Rainfall study of Dhubri district of Assam

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Rainfall is one of the important factors for crop planning under rainfed condition. Understanding of rainfall patterns of a region is of utmost importance for successful planning of crops in a profitable farming mode. The rainfall pattern decides the cultivation of crops, their varieties, adoption of cultural operations and harvesting of excess rainwater of any region (Kar, 2002). Generally cropping pattern is suggested considering the rainfall probability at different levels (Mahale and Dhane, 2003). Gupta *et al*. (1975) suggested that the rainfall at 80% probability could safely be taken as assured rainfall, while 50% probability is the medium limit for taking risk. Dhubri district is situated in the extreme western end of Assam. Monsoon usually starts from the month of June and continue up to early September. Paddy, wheat, other cereals, jute, mustard, pulses, vegetables etc. are the main crops of the district. As dependency of 70% population of the district is on agriculture and rainfall is deciding factor for success of rainfed agriculture, an attempt was made to understand the rainfall climatology by analyzing temporal and spatial rainfall distribution and its probability of occurrence of dry and wet spell and their distribution by analyzing rainfall data. Rainfall probability pattern has been studied by many scientists in India (Singh, *et al.,* 2009; Ravindrababu *et al*., 2010).

For the present study, daily rainfall data recorded at the meteorological observatory of Rupsi airport, Dhubri (Latitude 26.8, Longitude 89.5 and altitude 131ft) for a period of 24 years were used. Markov chain method was used to analyse dry and wet spell of rainfall for the district. Rainfall of 20mm per week is adequate for all the growth stages of all the crops grown. Thus, if in a given week the rainfall received is less than 20mm that week is dry week and vice versa. On this basis each week was categorized as dry and wet week and respective probabilities calculated. The incomplete gamma distribution was used to derive expected weekly rainfall at different probability levels (Lamba *et al*., 1990 and Jat *et al*., 2010). The data analysis was done by using Weathercock v 3.1 software developed by Central Research Institute for Dry Land Agriculture (CRIDA).

Analysis of weekly data of 24 years (1988-2012) indicated that both pre and post monsoon starts effectively from 13th standard meteorological week (SMW) (Mar. 26-Apr.1) and remains active upto 42nd SMW (Oct 22-Oct 28) in Dhubri district. Therefore, mean length of rainy season was 30 weeks (210 days).

The mean annual rainfall of Dhubri was found to be 2309 mm and it varied from lowest of 1376mm and highest of 3941mm with SD of 747mm and CV% of 32.4.The probability of dry week, P(D) was found to be 85% during most of the rainy season period (Fig.1).The initial dry spell results revealed that Dhubri district experiences dry spell during early and more during middle stages as compared to later stages. Similar trend were observed with consecutive dry spells also *i.e*., with probability of two consecutive dry weeks, P(2D), three dry weeks, P(3D) and four consecutive dry weeks, 4(D). The probability of occurrence of higher number of dry spell revealed that there is an importance of in situ moisture conservation measures and there may be need of supplementary irrigation during early and more during middle stages of rainy season. Thus it is an early warning to the farmers from early season drought. The probability of wet week were observed to be 96% in 22nd SMW during rainy season which indicates potential rainwater harvesting which may be utilized during dry spell. The consecutive wet weeks *i.e* P(2W), P(3W) and P(4W) revealed that there may be probability of getting rainwater for harvesting during rainy season. From the overall dry and wet spell analysis it was suggested that the sowing of dryland crops can be initiated during 15th and 16th SMW as 15th was found to be mean week of onset of rainy season.

The incomplete gamma distribution analysis for weekly rainfall at Dhubri region is given in the Fig.2. The results revealed that the expected weekly rainfall at 90%

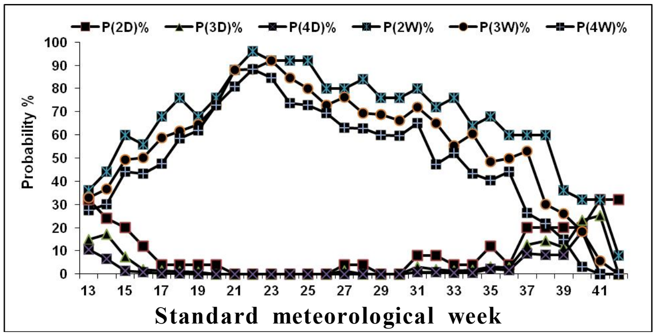

Fig.1: The consecutive dry and wet week probabilities

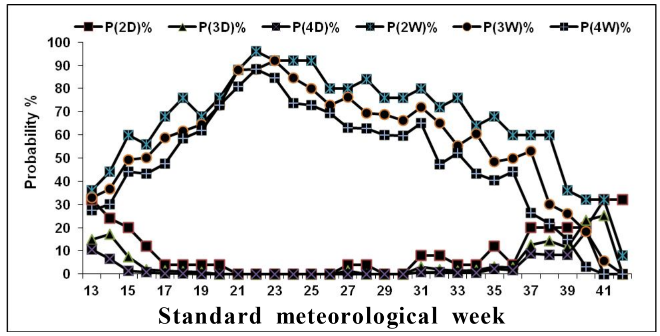

Fig.2: Weekly rainfall (mm) at different probabilities

probability ranged from 0.3 mm (42nd SMW) to 28.5mm (25th SMW). At 10% probability it varied from 65mm (42nd week) to 315.6mm (25th SMW). However, at 75% probability levels the range of rainfall values were 2.1mm to 59.9mm which is an indication of deficient rainfall during rainy season which indicates high risk of growing dryland crops which are likely to suffer by frequent dryspells. Mean and expected weekly rainfall at different probability level showed that the 25th week has the highest rain of 149.6mm and 12th week recorded the lowest rain of 16.1 mm. At 50% chances rainfall was assured in 12th week. A rainfall more than 50mm per week occurred from 20th SMW to 29th week at 50% probability level.

Crop planning

Paddy, wheat, other cereals, jute, mustard, pulses, vegetables etc. are the main crops of the district. From the analysis it can be revealed that at 50% probability level, minimum rainfall is received in every meteorological week .Field preparation and tillage operations could be initiated during 23rd and 24th week for better germination otherwise germination may be difficult. Transplanting should be completed in July last. 31st SMW (July 30-Aug 5) should be for tillering, 34th SMW (Aug 20-Aug2) for panicle initiation and 40th SMW (Oct1-Oct7) should be for maturity. Harvesting should be done in October. Short duration pulses like greengram, blackgram and oilseed crop is possible immediately after harvest of first crop. Hence, successful dependable rainfed cropping of cereals/pulses can be taken up during South West monsoon. The irrigation to the plantation crops like arecanut and coconut may be skipped to save water. All kinds of rainfed vegetable crops namely carrot, beans, turnip, radish can be grown as there is no long dry spell occurring at 50% probability level where every meteorological week receives minimum amount of rainfall. Higher probability value of P(W) and P(W/W) in this period indicate there are higher chance of week being wet.

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Book chapter

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Whole book

Murthy, V. R. K. (2002). "Basic Principles of Agricultural Meteorology". 1st Eds. (B. S. Publications, Hyderabad) pp.269.

Report/ bulletin

Mokashi, D. D., Jadhav, J. D., Khadtare, S. V., Rao, G. G. S. N., Bavadekar, V. R. and Kadam, J. R. (2008). "A two Decadal Research in Agrometeorology". AICRP on Agrometeorology, ZARS, Solapur.

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