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Study on the Interactions Between Lathyrus (*Lathyrus sativus* L.) and Agro-climatic Factors to Generate Weather Based Yield Forecasting Models

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Abstract

A field experiment was conducted with *Lathyrus sativus* L. sown on nine different dates at weekly interval to study the effect of weather parameters on yield and to develop regression equations involving agro-climatic factors to predict the yield. The experiment was carried out in *rabi* seasons in 2016-2017 in Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India. Simple correlation study between yield and weather parameters was conducted. Yield forecasting models were developed by stepwise regression technique. Highest biomass (4799.5 kg ha^{-1}) was produced by the crops sown on 16th November while biomass yield was the lowest (2524.0 kg ha^{-1}) in the crops sown on 21st December. Mean relative humidity during vegetative phase was positively correlated with grain yield (0.84*). On the contrary grain yield was negatively influenced by vapour pressure deficit at morning (-0.68*) and at afternoon (-0.88**) during reproductive phase. Mean air temperatures exhibited significant negative correlation during reproductive (-0.89**) and maturity phase (-0.86**) with biomass yield. Grain yield could be predicted by morning vapour presure at reproductive phase, heliothermal unit at maturity phase and maximum air temperature at pre-flowering phase with 99.9% predictability. Two models were developed to predict grain yield at the end of vegetative phase with 55.2% and 85.2% predictability respectively. It was clear from the experiment that yield of *Lathyrus* was significantly influenced by agro-climatic factors and weather parameters can be effectively used to predict yield before harvest.

Keywords: Agro-climatic factors, *Lathyrus,* pre-harvest forecasting, regression, yield.

1. Introduction

Lathyrus (*Lathyrus sativus* L.), also known as grass pea, chickling pea, khesari dal etc. is an important pulse crop of a great economic significance in India, Bangladesh, Pakistan, Nepal and Ethiopia. The genus *Lathyrus* has 187 species (Alkin et al., 1983) among which only one species *Lathyrus sativus* L. is widely cultivated as a food crop (Jackson and Yunus 1984). *Lathyrus* is a multi-purpose grain legume which is cultivated as food, feed and fodder crop which is mainly grown in residual moisture. *Lathyrus* can be cultivated in adverse weather conditions such as drought, excessive rainfall (Negere et al., 1994), poor quality of soil etc. (Palmer et al., 1989; Kaul et al., 1986; Rathod, 1989). Being a pulse crop, this crop has very deep tap root system and is able to fix a good amount of atmospheric nitrogen (Campbell et al., 1994). *Lathyrus* is mainly a winter season crop

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which is adapted to the subtropics or temperate climates (Haqqani et al., 1995). This crop can be grown well under the high temperatures of the subtropics as a winter crop and generally sown in October/ November and harvested in March (Sarwar et al., 1993). *Lathyrus* is more productive as compare to other pulse crops.

Climatic variability during the crop growing season alters the crop production to a greater extent because it affects the critical environmental factors like temperature, rainfall and evapotranspiration pattern etc. (Ruminta et al., 2018). Quality and quantity of production depend on both environmental and genetic factors. Crop production is adversely affected under changing climate (Szeles et al., 2018). Increased temperature condition during the present time has adverse effect on agriculture (Reddy and Sreenivas, 2016). Plant growth and development are influenced by air and canopy temperature and different crops has a different range of favourable temperature and temperature affects crop growth differently during different developmental phases (Hatfield et al., 2008). High temperature stress grain- filling period and consequently grain yield decreases (Barlow et al., 2015). Crop yield is severely affected by high temperature and drought stress (Hategekimana et al., 2018). Heat stress adversely affects the enzymatic activities in plants (Wilson et al., 2019). Other weather factors such as rainfall, evaporation, bright sunshine hours are the major limiting factors for dry matter production in tropical climate (Krishna Murthy et al., 2000). Crop yield is adversely affected by low temperature and moisture stress occurred during critical growth stages such as reproductive phase pod developmental phase, maturity phase etc. (Ramachandrappa et al., 1992). As the weather elements prevailing during each phenophase affect crop yield, pre-harvest yield forecasting models has been developed by generating regression equations yield and the weather parameters during different growth stages (Sarwar et al., 1993). Emergence of new pests in any crop is observed now a days as a consequences of climate change (Kamakshi et al., 2019).

This research work was carried out to study the crop weather interaction of *Lathyrus* crop. Critical agro-climatic parameters for yield and biomass prediction were identified. Pre-harvest forecasting models were developed to predict grain yield and above ground biomass yield involving yield and critical weather parameters.

2. Materials and Methods

2.1. Experimental details

Field experiment was conducted during the *rabi* seasons of 2016-2017 at Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India. The farm is situated at 22°58´ N latitude, 88°31´ E longitude and at an altitude of 9.75 m above the mean sea level. The average annual rainfall is 1457 mm, 85% of which is received from June to September. Mean monthly temperature ranges from 10 °C–37 °C. The experiment was laid out in simple Randomized Complete Block design (RCBD) with nine treatments (dates of sowing) and three replications. Plot size was 4.5×3.3 m^2. *Lathyrus* (Variety: Prateek) was sown on nine different dates at weekly interval (26th October, 2nd November, 9th November, 16th November, 23rd November, 30th November, 7th December, 14th December and 21st December).

2.2. Phenological and biometric observations

Seven distinct phenophases were identified namely emergence phase (P-1: sowing to 100% emergence), vegetative phase (P-2: 1st emergence to emergence of 1st flower bud), pre-flowering phase (P-3: sowing to emergence of 1st flower), reproductive phase (P-4: emergence of 1st flower bud to end of flowering), post-flowering phase (P-5: starting of flowering to end of flowering), pod developmental phase (P-6: emergence of 1st pod to end of pod initiation) and maturity phase (P-7: 1st matured pod to 100% maturity). After harvesting of crop, grain yield was recorded. Above ground biomass yield was determined by adding grain yield with the straw matter.

2.3. Agro-climatic factors

Daily maximum (T_{max}), minimum (T_{min}), mean (T_{mean}) air temperatures, and morning and afternoon soil temperatures (ST I and ST II respectively) recorded at 5, 15 and 30 cm soil depths, morning, afternoon, mean relative humidity (RH I, RH II and RH_{mean} respectively), vapour pressure (VP I, VP II and VP_{mean} respectively) vapour pressure deficits (VPD I, VPD II and VPD_{mean} respectively), total rainfall (R), total evaporation (E) and total bright sun shine hours (BSH) during each phenophase were collected from Principal Agrometeorological Observatory which is situated beside the experimental field. Three accumulated agrometeorological indices viz. growing degree day (GDD), photothermal unit (PTU) and heliothermal unit (HTU) occurring at different phenophases were evaluated (Khan et al., 2005).

Growing degree day (GDD)=$(T_m–T_b)$
Photothermal unit (PTU)=$[(T_m–T_b)\text{x}DL]$
Heliothermal unit (HTU)=$[(\bar{T}_m–T_b)\text{x}BSH]$

Where,
DL=Day length (Possible sunshine hours: from dawn to twilight)
BSH=Bright sunshine hours (Hour)
$\bar{T}_m$=Daily mean temperature in °C.
T_b=Base temperature of 5°C.

Day length for the latitude of the experimental field where Agrometeorological Observatory is situated was calculated following the table values of possible sunshine hours (Doorenbos and Pruitt, 1977).

Mean photo (Photo T) and mean nycto (Nycto T) temperatures were computed (Venkataraman and Krishnan, 1992)

Mean photo temperature=maximum temperature-0.40 (maximum temperature-minimum temperature)

Mean nycto temperature=minimum temperature+0.40 (maximum temperature-minimum temperature)

2.4. *Statistical analysis*

Grain and biomass yield data were statistically analyzed at p=0.05 level of probability using OP-STAT software. Correlation coefficients (r) between phenophase-wise mean and accumulated weather parameters and different agrometeorological indices and yield were determined (Gomez and Gomez, 1984). Regression equations were developed by stepwise regression through the SPSS 16.0 version for prediction of yield involving agro-climatic factors.

3. Results and Discussion

3.1. *Variation in grain yield and above ground biomass with varied sowing dates*

Grain yield and biomass yield averaged over two seasons were presented in Table 1. Grain yield showed an increasing trend from 26th October sown crop to 16th November sown crop and then grain yield started to decline. The highest above ground biomass (4799.5 kg ha^{-1}) was observed in crop sown on 16th November which was statistically at par with the biomass yields produced from the crops sown on 26th October, 2nd November, 9th November and 23rd November. The results further revealed that for every seven days delay in sowing beyond 16th November there were reductions in above ground biomass by 10.5%, 32.4%, 40.4%, 44.7% and 47.4% in crops sown on 23rd November, 7th December, 14th December and 21st December, respectively. Thus it is evident that crop sown beyond 23rd November were vulnerable to produce lesser biomass than the crop sown on 16th November. Biomass yield was lowest (2524.0 kg ha^{-1}) in the crops sown on 21st December. Grain yield was higher in case of early sowing. Both grain yield and biomass production was reduced when sowing was delayed (Kumar et al., 2008). It was earlier reported that grain yield of rice was decreased with delay in sowing dates (Dhaliwal et al., 2006; Mahajan et al., 2009). Reduction in dry matter production with delay in sowing time was also reported earlier in rice (Jagtap et al., 2016). Previous experimental results demonstrated that wheat yield decreased under late sown condition (Qamar et al., 2004; Rashid et al., 2004).

Table 1: Variation in grain yield (kg ha^{-1}) and above ground biomass (kg ha^{-1}) with varied sowing dates

Dates of sowing	Grain yield (kg ha^{-1})		Above ground biomass (kg ha^{-1})	
	Mean±Standard deviation	C.V. (%)	Mean±Standard deviation	C.V. (%)
26th Oct.	806.7±96.03	11.9	4178.8±204.12	4.9
2nd Nov.	840.0±54.61	6.5	4336.5±399.11	9.2
9th Nov.	865.3±73.99	8.6	4626.9±653.23	14.1
16th Nov.	994.4±122.52	12.3	4799.5±887.55	18.5
23rd Nov.	968.9±62.91	6.5	4295.2±968.97	22.6
30th Nov.	873.2±33.79	15.3	3243.5±637.49	19.7
7th Dec.	793.7±138.95	17.5	2858.8±538.61	18.8
14th Dec.	682.6±109.13	16.0	2654.3±264.30	10.0
21st Dec.	620.9±36.42	5.9	2524.0±138.76	5.5
CD (p=0.05)	162.343		1082.658	
SEm±	53.688		358.044	
CV (%)	11.2		16.6	

3.2. *Effects of agro-climatic factors on grain yield and above ground biomass*

The correlation studies between the grain yield and mean weather parameters (Table 2) showed that maximum, minimum and mean air temperature occurring during maturity phase exhibited significant negative correlation (T_{max}: -0.80**; T_{min}: -0.70*; T_{mean}: -0.75*) with grain yield. Significant negative correlation was exhibited between grain yield and morning relative humidity (-0.78*) during maturity phase while significant positive correlations were exhibited between the grain yield and afternoon relative humidity (0.78*) and mean relative humidity (0.84**) during vegetative phase. Morning, afternoon and mean actual vapour pressures of emergence, vegetative and pre-flowering phases had positive correlations whereas vapour pressures exhibited significant negative correlation of reproductive phase (VP I: -0.68*; VP II: -0.88**; VP_{mean}: -0.75*). Afternoon and mean vapour pressure deficit of emergence phase had positive correlation (VP II: 0.83**; VP_{mean}: 0.81*) with grain yield while during the remaining crop growing period vapour pressure deficits showed negative correlations. Soil temperatures at different depths during reproductive, pod developmental and maturity phases had adverse effects on the grain yield while grain yield was beneficially contributed by the soil temperatures during the other phenophases.

Correlation studies between the above ground biomass and mean weather elements (Table 3) showed that air temperature during the vegetative phase exhibited significant positive correlation (0.71*) with the biomass production. On the contrary, biomass production of grass pea was in highly significant negative correlation with air temperatures at reproductive (T_{max}: -0.86**; T_{min}: -0.91**; T_{mean}: -0.89**), pod developmental (T_{max}: -0.81**; T_{min}: -0.88**; T_{mean}: -0.85**) and maturity phase (T_{max}: -0.93**; T_{min}: -0.80**; T_{mean}: -0.86**). Biomass yield showed significant negative correlation with diurnal temperature range at vegetative phase (-0.68*) and significant positive correlation with diurnal temperature range at post-flowering phase (0.95**). Relative humidity during post-flowering phase showed very high significant positive correlation (RH I: 0.92**; RH II: 0.87**; RH_{mean}: 0.91**) with total biomass yield. Vapour pressure deficits during reproductive (VPD I: -0.77*; VPD II: -0.80**; VPD_{mean}: -0.84**) and pod developmental (VPD I: -0.84**; VPD II: -0.78*; VPD_{mean}:

Table 2: Correlation coefficients (r) between grain yield and mean weather parameters

Agro-climatic factors	P-1[a]	P-2[b]	P -3[c]	P-4[d]	P-5[e]	P -6[f]	P-7[g]
T_{max}	0.06	0.25	0.12	-0.52	0.53	-0.43	-0.80**
T_{min}	0.17	0.30	0.21	-0.65	-0.25	-0.55	-0.70*
T_{mean}	0.13	0.28	0.17	-0.58	0.32	-0.50	-0.75*
T_{range}	-0.23	-0.39	-0.32	0.38	0.66	0.50	0.47
RH I	-0.55	-0.08	0.03	0.14	0.57	0.04	-0.78*
RH II	-0.62	0.78*	0.48	-0.01	0.47	-0.24	-0.40
RH_{mean}	-0.62	0.84**	0.35	0.07	0.54	-0.07	-0.52
VP I	0.31	0.29	0.23	-0.68*	-0.65	-0.60	-0.71*
VP II	0.08	0.42	0.33	-0.88**	-0.78*	-0.74*	-0.66
VP_{mean}	0.22	0.35	0.27	-0.75	-0.70*	-0.65	-0.69*
VPD I	0.50	0.17	-0.01	-0.45	-0.38	-0.43	0.75*
VPD II	0.83**	-0.39	-0.64	-0.44	-0.40	-0.36	-0.13
VPD_{mean}	0.81**	-0.28	-0.48	-0.46	-0.41	-0.38	0.02
ST I at 5 cm	0.10	0.24	0.15	-0.60	0.10	-0.51	-0.61
ST II at 5 cm	0.12	0.24	0.14	-0.59	0.24	-0.50	-0.61
ST_{mean} at 5 cm	0.10	0.26	0.17	-0.58	0.40	-0.49	-0.53
ST I at 15 cm	0.08	0.20	0.06	-0.55	0.35	-0.45	-0.63
ST II at 15 cm	0.10	0.21	0.10	-0.58	0.26	-0.48	-0.60
ST_{mean} at 15 cm	0.11	0.27	0.17	-0.59	0.40	-0.49	-0.57
ST I at 30 cm	0.09	0.22	0.11	-0.58	0.25	-0.48	-0.63
ST II at 30 cm	0.11	0.22	0.12	-0.58	0.25	-0.49	-0.61
ST_{mean} at 30 cm	0.10	0.26	0.17	-0.58	0.40	-0.49	-0.58

*Significance of r≥0.67 at CD (*p*= 0.05) and **Significance of r≥0.80 at CD (*p*=0.01); [a]emergence phase; [b]vegetative phase; [c]pre-flowering phase; [d]reproductive phase; [e]post-flowering phase; [f]pod developmental phase; [g]maturity phase

-0.80**) phases exhibited significant negative correlation with the above ground biomass of grass pea. Grain yield was higher in case of early sowing.

Correlation coefficients (r) between yield and accumulated weather parameters and agrometeorological indices are shown in Tables 4 which revealed that BSH at maturity phase exhibited negative non-significant correlation with the total grain weight. Total rainfall and total evaporation at post-flowering phase had negative correlation with the grain weight, though the correlations were not significant. GDD (0.81**) and PTU (0.75*) at pre-flowering phases, registered significant positive correlations with grain yield. Grain yield of was negatively affected by the photo and nycto temperatures at reproductive, pod developmental and maturity phases. Grain yield showed significant negative correlation with photo and nycto temperatures during the maturity phase (Photo T: -0.75*; Nycto T: -0.73*). BSH at reproductive, post-flowering and pod developmental phase had significant positive correlations (Reproductive phase: 0.82**; post-flowering phase: 0.78*; pod developmental phase: 0.74*) with the biomass production (Tables 4). Total rainfall during reproductive phase (-0.69*) and total evaporation at per-flowering phase (-0.73*) had significant negative correlation with the above ground biomass. Correlation coefficients (r) between above ground biomass and accumulated weather parameters and agrometeorological indices showed that GDD, HTU and PTU at vegetative (GDD: 0.75*; HTU: 0.72*; PTU: 0.74*) and pre-flowering phases (GDD: 0.85**; HTU: 0.67*; PTU: 0.83**) exhibited significant positive correlation with above ground biomass. GDD accumulated during reproductive phase, exhibited significant positive correlation (0.68*) with biomass. Biomass production was beneficially influenced by photo temperature and nycto temperature of vegetative phase (Photo T: 0.71*; Nycto T: 0.71*). On the other hand, above ground biomass was adversely affected by photo temperature and nycto temperature of reproductive (Photo T: -0.88**; Nycto T: -0.89**) and pod developmental phase (Photo T: -0.84**; Nycto T: -0.86**).

Air temperatures during vegetative phase played positive role on biomass production while temperatures during

Table 3: Correlation coefficients (r) between above ground biomass and mean weather parameters

Agro-climatic factors	P-1[a]	P-2[b]	P -3[c]	P-4[d]	P-5[e]	P -6[f]	P-7[g]
T_{max}	0.25	0.71*	0.56	-0.86**	0.78*	-0.81**	-0.93**
T_{min}	0.51	0.71*	0.66	-0.91**	-0.32	-0.88**	-0.80**
T_{mean}	0.42	0.71*	0.62	-0.89**	0.49	-0.85**	-0.86**
T_{range}	-0.58	-0.68*	-0.55	-0.01	0.95**	0.35	0.55
RH I	-0.58	-0.53	0.07	0.13	0.92**	0.02	-0.87**
RH II	-0.37	0.87**	0.79*	0.32	0.87**	-0.01	-0.53
RH_{mean}	-0.50	0.69*	0.58	0.24	0.91**	0.01	-0.65
VP I	0.67*	0.70*	0.66	-0.90**	-0.90**	-0.88**	-0.84**
VP II	0.45	0.77*	0.74*	-0.90**	-0.94**	-0.91**	-0.78*
VP_{mean}	0.58	0.73*	0.70*	-0.91**	-0.92**	-0.90**	-0.81**
VPD I	0.80**	0.61	0.45	-0.77*	-0.60	-0.84**	0.83**
VPD II	0.71*	0.18	-0.19	-0.80**	-0.78*	-0.78*	-0.10
VPD_{mean}	0.77*	0.28	0.01	-0.84**	-0.78*	-0.80**	0.06
ST I at 5 cm	0.47	0.66	0.60	-0.89**	0.15	-0.86**	-0.79*
ST II at 5 cm	0.47	0.66	0.59	-0.89**	0.35	-0.86**	-0.80*
ST_{mean} at 5 cm	0.43	0.68*	0.60	-0.89**	0.62	-0.85**	-0.76*
ST I at 15 cm	0.37	0.66	0.53	-0.89**	0.44	-0.84**	-0.91**
ST II at 15 cm	0.44	0.65	0.55	-0.89**	0.34	-0.85**	-0.87**
ST_{mean} at 15 cm	0.44	0.69*	0.60	-0.89**	0.62	-0.85**	-0.77*
ST I at 30 cm	0.43	0.66	0.57	-0.89**	0.33	-0.85**	-0.86**
ST II at 30 cm	0.45	0.65	0.57	-0.89**	0.34	-0.85**	-0.84**
ST_{mean} at 30 cm	0.43	0.69*	0.60	-0.89**	0.61	-0.85**	-0.78*

*Significance of r≥0.67 at CD (p=0.05) and **Significance of r≥0.80 at CD (p=0.01); [a]emergence phase; [b]vegetative phase; [c]pre-flowering phase; [d]reproductive phase; [e]post-flowering phase; [f]pod developmental phase; [g]maturity phase

reproductive phase had negative role on dry matter yield which was confirmed by some earlier results (Agrawal et al., 2010; Rajput et al., 1986). In case delayed sowing, reproductive phase of the crop experienced higher temperature which caused abortion of floral parts and as a consequence grain yield was significantly reduced (Summerfield et al., 1984). Furthermore if the crop was sown beyond the optimum sowing window, higher air temperature resulted in poor pod filling during pod developmental phase and thus grain yield was reduced (Wang et al., 2006). Decline in yield of lentil due to increase in temperature was well documented (Dhuppar et al., 2012). Atmospheric moisture content had a significant negative effect on crop yield as indicated by the results of correlation studies which showed that vapour pressure deficit adversely effected crop yield and the same result was observed previously in cucumber (Barker et al., 1987). Vapour pressure deficit was lower when the relative humidity of the atmosphere was comparatively higher. Crop yield increased with increased relative humidity during middle stage of crop growth (Mortley et al., 2000). During post-flowering phase, biomass production increased with higher relative humidity (Mortley et al., 1994). On the other hand relative humidity during final stage of crop growth played a negative role on yield (Nagy, 1966). During pre-flowering stages vegetative growth of the crop enhanced under increased GDD accumulation and higher vegetative growth results in higher production of yield attributes and thereby higher yield whereas during late growth stages, biomass production was increased with increased accumulation of GDD which resulted in higher dry matter production (Meena et al., 2005).

3.3. Regression equations for prediction of grain yield and above ground biomass

In order to identify the best regression equation for prediction of grain yield and above ground biomass, stepwise regression analysis was performed by employing SPSS 10.0 and the results so obtained have been presented in the Table 5. 3 models were estimated for prediction of grain yield. In model 1, the estimated linear regression is significant at 1% level of significance, wherein the coefficient of determination

Table 4: Correlation coefficients (r) of grain yield and above ground biomass with accumulated weather parameters and agrometeorological indices

Parameters	Agro-climatic factors	P-1[a]	P-2[b]	P -3[c]	P-4[d]	P-5[e]	P -6[f]	P-7[g]
Grain yield (kg ha^{-1})	BSH	0.29	0.14	0.26	0.50	0.37	0.34	-0.16
	R	-0.07	0.06	0.06	-0.26	-0.24	-0.23	0.51
	E	0.15	-0.28	-0.47	0.37	-0.37	-0.01	-0.24
	GDD	0.01	0.54	0.81**	0.25	-0.02	0.02	-0.31
	HTU	0.42	0.33	0.43	0.30	-0.04	0.05	-0.53
	PTU	0.02	0.50	0.75*	0.14	-0.27	-0.18	-0.39
	Photo T	0.12	0.28	0.16	-0.57	0.40	-0.48	-0.75*
	Nycto T	0.14	0.29	0.18	-0.59	0.26	-0.50	-0.73*
Above ground bio-mass (kg ha^{-1})	BSH	0.13	0.25	-0.19	0.82**	0.78*	0.74*	0.22
	R	0.22	0.39	0.39	-0.69*	-0.60	-0.55	0.41
	E	0.37	-0.01	-0.73*	0.12	-0.04	0.29	0.27
	GDD	0.25	0.75*	0.85**	0.68*	0.48	0.49	0.20
	HTU	0.49	0.72*	0.67*	0.65	0.47	0.49	-0.13
	PTU	0.28	0.74*	0.83**	0.59	0.25	0.30	0.12
	Photo T	0.39	0.71*	0.61	-0.88**	0.59	-0.84**	-0.87**
	Nycto T	0.44	0.71*	0.63	-0.89**	0.40	-0.86**	-0.84**

*Significance of r≥0.67 at CD (*p*=0.05) and **Significance of r≥0.80 at CD (*p*=0.01); [a]emergence phase; [b]vegetative phase; [c]pre-flowering phase; [d]reproductive phase; [e]post-flowering phase; [f]pod developmental phase; [g]maturity phase

Table 5: Regression equations involving grain yield (kg ha^{-1}) and agroclimatic parameters

Parameters	Model	Regression equations	Adjusted R^2	Standard error of estimates
Grain yield (kg ha^{-1})	1	$Y=2795.218–152.172 X_1$	0.740**	61.8072
	2	$Y=2997.075–146.485 X_1$ - 0.130 X2	0.990**	12.1228
	3	$Y=3441.016–163.595 X_1–9.82E-02 X_2–10.765 X_3$	0.999**	3.8648
Above ground biomass (kg ha^{-1})	1	$Y =-2400.573 + 415.098 X_4$	0.892**	297.1223
	2	$Y=-2531.322 + 330.045 X_4+237.097 X_5$	0.975**	141.9086
	3	$Y=586.829+230.704 X_4$+231.182 X5–129.517 X_6	0.992**	81.5541
	4	$Y = 2576.357+211.360 X_4+173.360 X_5 – 204.170 X_6–3.903 X_7$	0.998**	37.3946

**=Significant at CD (*p*= 0.01); X_1: AVP I at reproductive phase; X_2: HTU at maturity phase; X_3: Tmax at pre-flowering phase; X_4: Temperature range at post-flowering phase; X_5: Mean vapour pressure deficit at emergence phase; X_6: Minimum air temperature at reproductive phase; X_7: Rainfall at vegetative phase

(adjusted R^2) of the model was 0.740** which indicated that the model is able to account for 74.0% of the total variability in the grain yield through a linear function involving afternoon actual vapour pressure (VP II) at reproductive phase. Model 2 (adjusted R^2 = 0.990**) which added accumulated heliothermal unit (AHTU) at maturity phase over model 1, could explain that 99.0% of the total variability in the grain yield. Model 3 (adjusted R^2=0.999**) included maximum temperature (T_{max}) at pre-flowering phase over the second model. From the results it was clear that the rate of increment in predictability of grain yield was increased by 25% in model 2 over model 1 while in model 3, predictability was only 0.9% more over model 2.

For prediction of above ground biomass using agro-climatic factors, 4 models were computed. The first model having adjusted R^2 value of 0.892** involved temperature range (T_{range}) at post-flowering phase and the model was able to predict 89.2% of the total variability in biomass yield. In model 2 (adjusted R^2=0.975**), the computed linear regression model was found to include mean vapour pressure deficit (VPD_{mean}) at emergence phase over model 1. The third model (adjusted R^2=0.992**) added minimum air temperature (T_{min}) at reproductive phase over model 2. In model 4 (adjusted R^2=0.998**), total rainfall (R) at vegetative phase was added as explanatory variables. Model 1, using one predictor variable was able to explain 89.2% of the total variation in above ground biomass. Model 2 which include two predictor variables, the rate of increase in predictability in terms of adjusted R^2 values is only 8.3% more over that that in model 1. The model 3 and 4 which included 3 and 4 predictor variables, respectively, the rate of increase in adjusted R^2 were very low amounting to 1.7% and 0.6%, respectively.

3.4. Regression equations for pre-harvest forecasting of grain yield and above ground biomass at vegetative phase

Regression equations for prediction of grain yield and biomass yield of *Lathyrus* at the end of vegetative phase has been developed and presented in Table 6. Two models were developed to predict grain yield at the end of vegetative phase. Model 1 is significant at 5% level of significance with adjusted R^2 value of 0.552* which indicated that the model could account for 55.2% of the total variability in the grain yield by using temperature range (T_{range}) during vegetative phase. The second model (adjusted R^2=0.852**) added afternoon relative humidity (RH II) occurring during vegetative phase over the first model. The step wise regression technique gave only one model (adjusted R^2 = 0.729**) for prediction of above ground biomass at the end of vegetative phase and the model used afternoon relative humidity (RH II) of vegetative phase.

3.5. Regression equations for pre-harvest forecasting of grain yield and above ground biomass at reproductive phase

Table 6: Regression equations for pre-harvest forecasting of grain yield and above ground biomass using agro-climatic factors of vegetative phase

Parameters	Model	Regression equations	Adjusted R^2	Standard error of estimates
Grain yield (kg ha^{-1})	1	$Y=-908.298+31.614X_1$	0.552*	80.8329
	2	$Y=-5152.002+67.297X_1+147.843X_2$	0.852**	46.6618
Above ground biomass (kg ha^{-1})	1	$Y=-10835.0+265.194X_3$	0.729**	470.7221

*: Significant at CD (p=0.05); **: Significant at CD (p=0.01); X_1: Temperature range; X_2: Afternoon relative humidity; X_3: afternoon relative humidity

Table 7 represents the regression equations for prediction of grain yield and biomass yield at the end of reproductive phase. Two models were developed to predict grain yield. Model 1 having adjusted R^2 value of 0.742** could account for 74.2% of the total variability in the grain yield by using afternoon actual vapour pressure (VP II) during reproductive phase. The second model (adjusted R^2=0.919**) added accumulated rainfall (R) at reproductive phase over model 1. Above ground biomass could be predicted by one model (adjusted R^2=0.809**) using mean actual vapour pressure (VP_{mean}) of reproductive phase.

Table 7: Regression equations for pre-harvest forecasting of grain yield and above ground biomass using agro-climatic factors of reproductive phase

Parameters	Model	Regression equations	Adjusted R^2	Standard error of estimates
Grain yield (kg ha^{-1})	1	$Y = 2792.415-152.007X_1$	0.742**	61.3593
	2	$Y = 3478.778-212.535X_1+9.307X_2$	0.919**	34.3752
Above ground biomass (kg ha^{-1})	1	$Y= 13406.500-724.243X_3$	0.809**	395.709

**: Significant at CD (p=0.01); X_1: Afternoon actual vapour pressure; X_2: Accumulated rainfall; X_3: Mean actual vapour pressure

Development of regression models for prediction of crop yield with the help of agro-climatic factors prevailing during the crop growing season was reported earlier (Kandiannan et al., 2002, Sharma et al., 2004). Forecasting of crop yield before harvest was also documented previously (Smith and Gooding., 1999).

4. Conclusion

Grain yield and dry matter yield of *Lathyrus* were significantly influenced by the growing season weather parameters. Yield was adversely affected by higher temperature during reproductive stages of crop growth and onwards. Final grain yield and biomass production could be successfully predicted at the end of vegetative as well as reproductive phase using the agro-climatic factors prevailing only during the vegetative and reproductive phase respectively.

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6. References

Agrawal, K., Bhadauria, U.P.S., Jha, A., Jain, S., 2010. Crop weather relationship studies on chickpea for improving crop adaptation to climate change. International Journal

Tropical Agriculture 28, 239–242.
Alkin, R., Macfarlance, T.D., White, R.J., Bisby, F.A., Adey, M.E., 1983. Names and synonyms of species and subspecies in the Vicieae. Issue 2, Vicieae Database Project Publication No. 2, Southampton.
Barker, J.C., Welles, G.W.H., Van Uffelen, J.A.M., 1987. The effects of day and night humidity on yield and quality of glasshouse cucumbers. Journal of Horticultural Science 62, 363–370.
Barlow, K.M., Christy, B.P., O'leary, G.J., Riffkin, P.A., Nuttall, J.G., 2015. Simulating the impact of extreme heat and frost events on wheat crop production: A review. Field Crops Research 171, 109–119.
Campbell, C.G., Mehra, R.B., Agrawal, S.K., Chen, Y.Z., Abd EL Moneim, A.M., Kawaja, H.I.T., Yadav, C.R., Tay, J.U., Araya, W.A., 1994. Current status and future strategy in breeding grasspea (*Lathyrus sativus*). Euphytica 73, 167–175.
Dhaliwal, L.K., Hundal, S.S., Chahal, S.K., Aneja, A., 2006. Effect of conventional and furrow planting methods on radiation interceptopn, growth and yield of rice paddy. Proceedings of the international workshop on Water saving practices in rice paddy cultivation 14–15 September, Kaulalumpur (Malalysia)
Dhuppar, P., Subhash, C., Chintapalli, B.B., Rao, D.S., 2012. Lentil Crop Production in the Context of Climate Change: An Appraisal. Indian Research Journal of Extension Education, Special Issue, 33–35.
Doorenbos, J., Pruitt, W.O., 1977. Guidelines for predicting crop water requirements. In: FAO Irrigation and Drainage Paper No. 24. FAO, Rome, 144.
Gomez, K.A., Gomez, A.A., 1984. Statistical procedures for agricultural research. In John wiley and sons, New York. 680.
Haqqani, A.M., Arshad, M., 1995. Crop status and genetic diversity of grasspea in Pakistan, 59-65 in Lathyrus Genetic Resources in Asia. Proceedings of a Regional Workshop, 27–29 December 1995, Indira Gandhi Agricultural University, Raipur, India. In: Arora, R.K., Mathur, P.N., Riley, K.W., Adham, Y. (Eds.), IPGRI Office for South Asia, New Delhi, India, 59–65.
Hategekimana, P., Thobunluepop, P., Saorobol, E., Sarobol, N., 2018. Evaluation the adaptability of different corn cultivars under drought stress at different growth stages. Journal of Agronomy 17, 224–233.
Hatfield, J.L., Boote, K.J., Fay,P., Hahn,L., Izaurralde,C., Kimball, B.A., Mader,T., Morgan, J., Ort,D., Polley,W., Thomson, A., Wolfe, D., 2008. Agriculture. In The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. U.S. Climate Change Science Program and the Subcommittee on Global Change Res., Washington, DC.
Jackson, M.T., Yunus, A.G., 1984. Variation in the grass pea (*Lathyrus sativus* L.) and wild species. Euphytica 33, 549–559.
Jagtap, D.N., Chavan, V.G., Mahadkar, U.V., Chavan, S.A., 2016. Effect of sowing times on the yield and yield attributes of rice (*Oryza sativa* L.) varieties. Indian Society of Coastal Agricultural Research 34, 27–30.
Kamakshi, N., Sagar, D., Jayalakshmi, V., Chander, S., 2019. Weather based prediction model for beet army worm (*Spodoptera exigua* Hubner) in chickpea. Journal of Environmental Biology 40, 84–88.
Kandiannan, K., Karithikeyan, R., Krishnan, R., Kailasam, C., Balasubramanian, T.N., 2002. A crop-weather model for prediction of rice yield using an empirical- statistical technique. Journal of Agronomy and Crop Science 188, 59–62.
Kaul, A.K., Islam, M.Q., Hamid, A., 1986. Screening of Lathyrus germplasm of Bangladesh for BOAA content and some agronomic characters. *Lathyrus* and Lathyrism, In: Kaul, A.K., Combes, D. (Eds.), Third World Medical Research Foundation, New York, 130–141.
Khan, S.A., Maity, G.C., Das, L., 2005. Prediction of grain yield of *kharif* rice based on thermal, heliothermal and photothermal units prevailing during different phases of growth. Environment and Ecology 23, 545–552.
Krishna Murthy, S.K., Yogeswara Rao, A., 2000. Correlation between weather parameters at different phenophases and growth and yield parameters of groundnut (*Arachis hypogaea* L.). Annals of Arid Zone 39, 29–33.
Kumar, A., Pandey, V., Shekh, A.M., Kumar, M., 2008. Growth and yield response of soybean (*Glycine max* L.) in relation to temperature, photoperiod and sunshine duration at Anand, Gujarat, India. American Eurasian Journal of Agronomy 1, 45–50.
Mahajan, G., Bharaj, T.S., Timsina, J., 2009. Yield and water productivity of rice as affected by time of transplanting in Punjab, India. Agricultural Water Management 96, 25–32.
Meena, R.P., Singh, S.P., Beniwal, R.K., 2005. Correlation of Weather Parameters with Growth, Yield Attributes and Pod Yield of Groundnut (*Arachis hypogaea* L.) during Different Phenophases under Irrigated Condition of Western Rajasthan. Annals of Arid Zone 44, 23–28.
Mortley, D.G., Bonsi, C.K., Loretan, P.A., Hill, W.A., Morris, C.E., 1994. Relative humidity influences yield, edible biomass, and linear growth rate of sweetpotato. Hortscience 29, 609–610.
Mortley, D.G., Bonsi, C.K., Loretan, P.A., Hill, W.A., Morris, C.E., 2000. High relative humidity increases yield, harvest index, flowering, and gynophore growth of hydroponically grown peanut plants. Hortscience 35, 46–48.
Nagy, J., 1966. Phenological studies on peas in relation to temperature. Hort' Abstr'. 36, 775 .
Negere, A., Mariam, S.W., 1994. An overview of grass pea (*Lathyrus sativus*) production in Ethiopia. Nutrition,

Neurotoxins and Lathyrism: The ODAP Challenge In: Abegaz, B.M., Haimanot, R.T., Palmer, V.S., Spencer, P.S. (Eds.), Third World Medical Research Foundation, New York. 67–72.

Palmer, V.S., Kaul, A.K., Spencer, P.S., 1989. International Network for the Improvement of *Lathyrus sativus* and the Eradication of Lathyrism (INILSEL): A TWMRF initiative. The Grass Pea: Threat and Promise. Proc. of the International Network for the Improvement of Lathyrus sativus and the Eradication of Lathyrism. In Spencer P. Third World Medical Research Foundation, New York, 219–223.

Qamar, M., Shafiullah, Makeen, S., 2004. Genetic variability among wheat cultivars and effect of planting dates on grain and straw yield under double cropping zone of Northern areas of Pakistan. Sarhad Journal of Agriculture 20, 99–102.

Rajput, R.L., Shrivastav, V.K., Yadav, R.P., 1986. Response of chickpea to sowing dates. Indian Journal of Agronomy 31, 95–96.

Ramachandrappa, B.K., Kulkarni, K.R., Naniappa, H.Y., 1992. Stress day index for scheduling irrigation in summer groundnut (*Arachis hypogaea* L.). Indian Journal of Agronomy 37, 276–279.

Rashid, M.H., Samanta, S.C., Biswas, P., Mannan, M.A., Zaman, A.K.M.M., 2004. Performance of thirty wheat genotypes under late sown conditions in southern region of Bangladesh. Asian Journal of Plant Science 3, 286–289.

Rathod, K.L., 1989. Status of *Lathyrus sativus* L. in India with special reference to Madhya Pradesh. Grass pea: Threat and Promise. Proceedings of the International Network for the Improvement of *Lathyrus sativus* and the Eradication of Lathyrism, In: Spencer, P.S. (Ed.), Third World Medical Research Foundation, New York, 168–174.

Reddy, D.R., Sreenivas, G., 2016. Climate Change Impact on Agriculture in India. International Journal of Economic Plants 3, 23–26

Ruminta, Handoko, Nurmala, T., 2018. Decreasing of paddy, corn and soybean production due to climate change in Indonesia. Journal of Agronomy 17, 37–47.

Sarwar, C.D.M., Sarkar, A., Murshed. A.N.M.M., Malik, M.A., 1993. Variation in natural population of grass pea. in *Lathyrus sativus* and Human Lathyrism: Progress and Prospects. Proc. 2nd Int. Colloq. Lathyrus/ Lathyrism, Dhaka, 10-12 December 1993. University of Dhaka, 161–164.

Sharma, A., Sood, R.K., Kalubarme, M.H., 2004. Agrometeorological wheat yield forecast in Himachal Pradesh. Journal of Agrometeorology 6, 153–160.

Smith, G.P., Gooding, M.J., 1999. Models of wheat grain considering climate cultivar and nitrogen effects. Agricultural and Forest Meteorology 94, 159–170.

Summerfield, R.J., Hadley, P., Roberts, E.H., Minchin, F.R., Rawsthrone, S., 1984. Sensitivity of chickpea (*Cicer arietinum* L.) to hot temperatures during the reproductive period. Experimental Agriculture 20, 77–93.

Szeles, A., Horvath, E., Vad, A., Harsanyi, E., 2018. The impact of environmental factors on the protein content and yield of maize grain at different nutrient supply levels. Emirates Journal of Food and Agriculture 30, 764–777

Venkataraman, S., Krishnan, A., 1992. Crops and Weather. Indian Council of Agricultural Research, 302.

Wang, J., Gan, Y.T., Clarke, F., McDonald, C.L., 2006. Response of chickpea yield to high temperature stress during reproductive development. Crop Science 46, 2171–2178.

Wilson, R.A., Gupta, S., Sangha, M.K., Kaur, G., 2019. Effect of heat stress on enzymatic and non-enzymatic antioxidants in *Brassica rapa.* Journal of Environmental Biology 40, 119–124.