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Short Communication

Black pepper (*Piper nigrum* L.) yield estimates using crop weather model

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Black pepper is a perennial crop. Flushing starts during pre-monsoon showers and subsequent biotic events such as spike initiation and elongation, berry formation and development commence during rainy season and complete its growth and development cycle by December/January (Mathew *et al*., 2006). March is the end of harvest and beginning of dry hot summer (March–May). During dry hot summer, crop experiences dry period and coincide with high temperature. Annual cycle of black pepper broadly divided into five phases. It starts with (i) lag period (March-May), it is interval between harvest and subsequent spike initiation, (ii) spike emergence and flower bud differentiation (June-July), new leaf accompanied by spike, (iii) spike enlargement and berry formation (August-October), (iv) berry development (November-December), (v) maturity and harvest (January-February). These phases may overlap and vary depending on rainfall distribution, variety and location (Kandiannan *et al.,* 2011; Krishnamurthy *et al*., 2011). Pepper requires adequate rainfall and humidity for its growth and development. The crop tolerates a temperature range of 10-40^{0}C and the ideal temperature is 23-32^{0}C with an average of 28^{0}C. Optimum soil for root growth is 26-28^{0}C. It successfully grows between 20^{0}North and South Latitude and up to 2000 m MSL (Radhakrishnan *et al.,* 2002). Crop weather analysis model (CWAM) helps to understand the crop association (yield) with varying weather variables using second-degree multiple-regression equation (Huda *et al.,* 1975). The crop-weather relationship is well established for diversified crops grown in Lower Gangetic Plains (Banerjee, 2006; Chakraborty *et al.,* 2017; Sattar *et al.,* 2018), but in this region very less focus was given for black pepper. Hence, objective of the present research work is to evaluate the most accurate relationship between the yield of black pepper and different weather variables using CWAM.

The different weather variables were collected from Agro-met observatory maintained at Department of Agricultural Meteorology and Physics, Faculty of Agriculture, Bidhan Chandra Krishi Viswvavidyalaya, Mohanpur, Nadia, West Bengal, India. Daily weather data for seven years (2012-13 to 2018-19) and weekly mean for all variables were calculated except for rainfall, for that weekly total has been worked out and used. The different weather variables used in the study are maximum temperature (^{0}C) (TMAX), minimum temperature (^{0}C) (TMIN), weekly total rainfall mm (RAIN), morning relative humidity (%) (RHMRN), afternoon relative humidity (%) (RHAFN), wind speed (km hr^{-1}) (WIND), pan evaporation (mm) (EPN) and bright sunshine hours (hrs) (BSSH). The data regarding to annual fresh berry yield of black pepper hybrid Panniyur-1 for the period 2012-13 to 2018-19 of experimental site was collected and crop-weather relationship has been worked out.

Exact mathematical relations for crop yield, rainfall, maximum and minimum temperature, maximum and minimum relative humidity are not known and it is assumed that a second-degree multiple-regression equation would be sufficiently flexible to express the relation. The nature of association between black pepper yield and weather during annual cycle established by adopting following second degree polynomial equation used by Huda *et al*. (1975):

$$Y = A0 + a1\sum_{i=1}^{n=52} t_i^0\, x1 + a2\sum_{i=1}^{n=52} t_i^1\, x1 + a3\sum_{i=1}^{n=52} t_i^2\, x1 + DT$$

Where, Y = black pepper fresh berry yield (kg/vine); x1= any climatic variable within any given seven day period; ti = the number of each of seven day periods (it is 1 for the period from 5th- 11th March (10th Standard meteorological week (SMW)) and 52 for the period from subsequent February 26th - 4th March (9th SMW); n = 52 seven day periods in a given crop season; T = year number; A0, a1, a2, a3 and D = constants.

Table 1: Annual yield of Black pepper (Hybrid Panniyur-1) grown in New Alluvial Zone of West Bengal

Years	Berry yield (kg vine^{-1})
2012-13	0.541
2013-14	1.186
2014-15	0.925
2015-16	1.728
2016-17	2.454
2017-18	2.592
2018-19	2.069

Panniyur-1 variety of black gram yielded very low (0.541 kg vine^{-1}) in 2012-13, followed by 2014-15 (0.925 kg vine^{-1}) and the maximum berry yield (2.592 kg vine^{-1}) was recorded in 2017-18, followed by 2016-17 (2.454 kg vine^{-1}) and 2018-19 (2.069 kg vine^{-1}). The berry yield was increasing during the study period from 2012-13 to 2018-19 because pepper vines are in early stage and yield is yet to be stabilized (Table 1). However, decline in berry yield (0.925 kg vine^{-1}) in 2014-15 and 2018-19 (2.069 kg vine^{-1}) when compared to previous year could be attributed due to adverse weather or incidence of pest and diseases. Rainfall varied between 1121 to 1071 mm during the annual cycle of black pepper. To elucidate the impact of weather on black pepper yield, the distribution of weather variables during the black pepper cropping pattern is discussed first and then its impact on pepper yield.

The mean of weekly maximum temperature (TMAX) during the black pepper growing cycle varied from 23.7^{0}C to 37.9^{0}C. It was recorded at the beginning that TMAX was above 30^{0}C and reached maximum as high as 37.9^{0}C during the 16th week (16-22 April). An average of 32.7^{0}C was recorded during the peak monsoon period, i.e. July (27-30 SMW) which is considered as very crucial for the spike emergence and enlargement. However, it reached as low as the 23.7^{0}C during end of 52 SMW (25-31 December). After December, TMAX gradually increased up to 31.8^{0}C till the end of annual cycle in 9 SMW (26 Feb - 04 March). The TMAX was compatibly stabilized during the period of 26 SMW (25 June - 01 July) to 38 SMW (17-23 September) which includes peak monsoon period and it varied from 31.5^0 to 33.9^{0}C.

The weekly minimum temperature (TMIN) was 18.3^{0}C at the beginning of annual cycle, and increased gradually maximum (28.0^{0}C) during 23rd week (04-10 June). Thereafter, TMIN started declining from 26.1^{0}C at 38th week (17-23 September) to minimum as low as 09.5^{0}C during 2nd week of annual cycle (08-14 January). Subsequently, it kept on increasing in the later weeks up to 17.6^{0}C till an end of annual cycle. The minimum temperature was highly stabilized during the period of 24 SMW (11-17 June) to 39 SMW (24-30 September) which includes peak monsoon period and it varied from 26.0^0 to 26.9^{0}C.

Considering the total rainfall distribution for each 7 days' period for seven years, the 10th standard week (05-11 March was considered as beginning of the annual black pepper cycle) and first good showers of mean weekly total RAIN at this week was as low as 0.79 mm only. The increasing trend in the RAIN was recorded from 18 - 42 SMW (30 April - 06 May to 15-21 October) of about 20.96 mm to 21.63 mm, respectively. It may, however, be as high as the maximum of 97.97 mm during 30 SMW (23-29 July) which is a peak monsoon period. Subsequently, it reached as low as the minimum of 0.00 mm during 47, 48 and 52 SMW, respectively. It was also seen that during the maturity period *i.e.,* at end of an annual cycle, i.e. 01 SMW (01-07 January) to 09 SMW (26 Feb - 04 March), the rainfall was average of 3.24 mm to 17.61 mm.

The mean of weekly morning relative humidity (RHMRN) during the pepper growing season varied from 86% to 97%. RHMRN during initial week was 87%, and increased gradually up to July end (97%), dropped for two weeks and again increased subsequently to 97% during 3-9 September, and decreased gradually. At the 9 SMW (26 Feb - 04 March) during an end of the annual cycle of black pepper, RHMRN was 91%. The minimum RHMRN was marked on the 11 SMW (12-18 March) as low as 86%, respectively.

Afternoon relative humidity (RHAFN) range was 38% to 85% at the 11 SMW (12-18 March) and 30 SMW (23-29 July). Afternoon relative humidity during initial week was 41% at 10 SMW (05-11 March), and increased gradually reaching maximum 85% during 30 SMW (23-29 July). Thereafter, it declined towards end of the cycle reaching 48% at 9 SMW (26 Feb-04 March). The RHAFN was slightly varying during the period of 26 SMW (25 June-01 July) to 34 SMW (20-26 August) which is peak monsoon period. During this period the RHAFN varied from 79% to 85%, respectively.

Mean weekly wind speed (WIND) varied between 0.04 and 1.32 km/hr and the evaporation varied between 0.98 and 4.64 mm per day during annual pepper cycle. The

Table 2: Multiple regression equations to predict black pepper yield (Yin kg vine^{-1}) based on weather variables

Weather variables	Regression equation	R^2
TMAX	$Y = 0.5188 - 0.0058 \sum_{i=1}^{n=52} t_i^0 x1 + 0.0001 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0000 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3214\ T$	0.76
TMIN	$Y = 0.1998 + 0.0155 \sum_{i=1}^{n=52} t_i^0 x1 - 0.0007 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0000 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3215\ T$	0.77
RAIN	$Y = 0.3510 - 0.0038 \sum_{i=1}^{n=52} t_i^0 x1 + 0.0002 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0000 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3218\ T$	0.77
RHMRN	$Y = -1.0176 + 1.1759 \sum_{i=1}^{n=52} t_i^0 x1 - 0.0070 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0001 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3172\ T$	0.78
RHAFN	$Y = -0.0589 + 0.6338 \sum_{i=1}^{n=52} t_i^0 x1 - 0.0148 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0002 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3228\ T$	0.78
WIND	$Y = 0.3633 + 0.0706 \sum_{i=1}^{n=52} t_i^0 x1 - 0.0016 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0001 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3141\ T$	0.77
EP	$Y = 0.4418 - 0.0454 \sum_{i=1}^{n=52} t_i^0 x1 + 0.0024 \sum_{i=1}^{n=52} t_i^1 x1 - 0.0001 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3220\ T$	0.77
BSSH	$Y = 0.4590 - 0.0127 \sum_{i=1}^{n=52} t_i^0 x1 - 0.0002 \sum_{i=1}^{n=52} t_i^1 x1 + 0.0000 \sum_{i=1}^{n=52} t_i^2 x1 + 0.3211\ T$	0.77

sunshine hours during initial week was 8.13 during middle of March and again increased maximum during the fortnight of April. But, it decreased to minimum in July, thereafter it gradually increased during October and again decreased. From, December fortnight onwards again it increased subsequently towards the end of the annual cycle.

The weekly average maximum and minimum temperature (TMAX and TMIN), weekly average total rainfall (RAIN), morning and afternoon relative humidity (RHMRN and RHAFN), wind speed (WIND), evaporation (EPN) and bright sunshine hours (BSSH) of 52 weeks of the annual cycle of black pepper and the yield for 07 years, *i.e.*, from 2012-13 to 2018-19, were analysed. The multiple regression equations obtained through regression models had brought the magnitude of association for weather parameters and berry yield with their coefficient of determination in the order *i.e.*, RHMRN > RHAFN > WIND > BSSH > RAIN > EPN > TMIN >TMAX. These experimental findings were in consonance with the findings of Kandiannan *et al.* (2011) which showed the significant association and brought out the magnitude of association of weather parameters with black pepper yield in the order, *i.e.*, RHMAX > RAIN > TMIN > TMAX > SUNS > WIND > RHMIN > EVPN.

The crop weather analysis models (CWAMs) in the form of multiple regression equation were obtained for all the eight weather parameters used for the study and shown in Table 2.

The results showed that the adverse effect of TMAX during lag period (March-May) was 0.006 kg vine^{-1} and decreased slightly up to 0.004 kg vine^{-1} during the spike

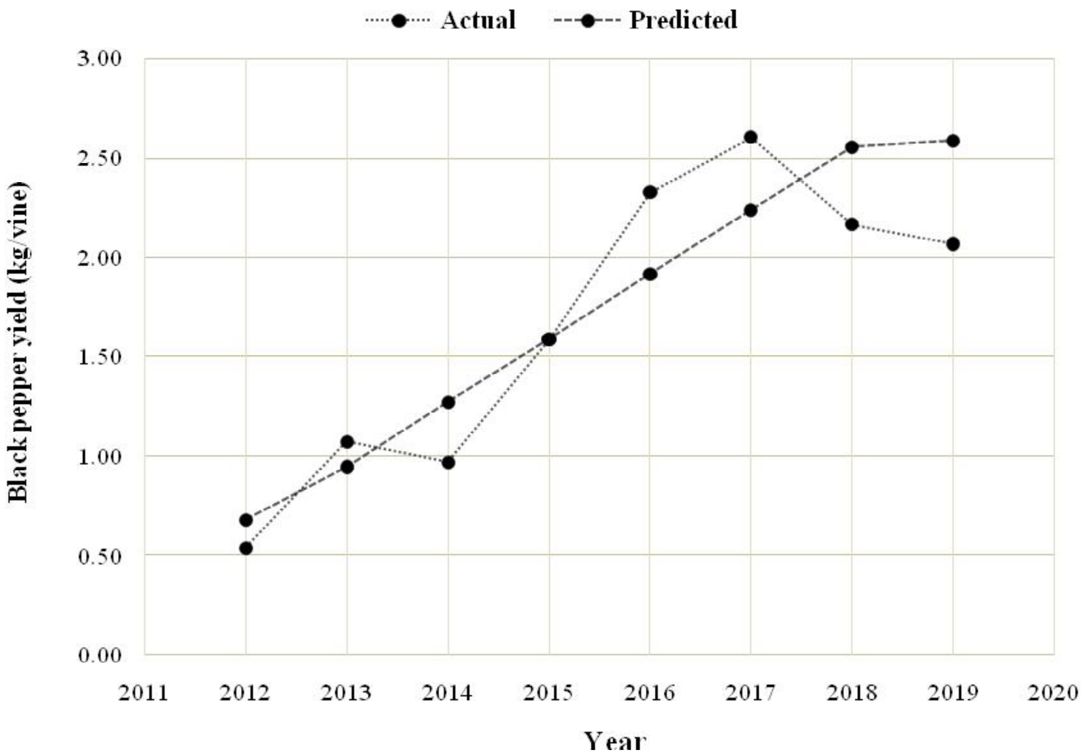

Fig. 1: Actual and predicted yield for different years using the regression equation for rainfall effects on black pepper yield

enlargement and berry formation stage (August-October). However, the beneficial effect of TMAX on net change in yield (kg vine^{-1}) could be obtained only if the TMAX was 1°C less than the normal. Kandiannan *et al*., (2011) also reported in their results that TMAX increase by one unit than the normal during end of April would adversely affect the yield. Likewise, if the TMIN during annual cycle of pepper was 1^{0}C more than the normal, the beneficial effect on yield was observed. The results showed that the beneficial effect on yield due to increase in the TMIN was 0.015 kg vine^{-1} during the lag period (March-May), 0.005 kg vine^{-1} during the spike enlargement and berry formation stage (August-October) and 0.013 kg vine^{-1} during the maturity and harvesting stage (January-February) of black pepper. If the RAIN was 1 mm more than the total during its annual cycle, the adverse effect was observed on the black pepper yield initially. This adverse effect was 0.004 kg vine^{-1} during the 10th Met week (5-11 March). It also decreased in the following weeks and was 0.003 kg vine^{-1}, 0.002 kg vine^{-1} and 0.001 kg vine^{-1} up to 30 SMW (23-29 July), respectively. During the 32 SMW onwards, however, the increase in weekly total rainfall by 1 mm more than the normal increased the yield of black pepper. The beneficial effect on yield was 0.001 kg vine^{-1} and continued up to 07 SMW in the annual cycle of black pepper. These experimental findings were in consonance with the findings of Pillay *et al*. (1986) where the rainfall of 70 mm received in 20 days during May-June has been sufficient for triggering off flushing and flowering process in black pepper. If the amount of rainfall is less than 10 mm in the critical period, it will adversely affect the berry development and ultimately yield. Kandiannan *et al*. (2011) has observed the nature of relationship indicates that rainfall beyond normal during initial period of annual cycle was harmful or would reduce the yield and rainfall excess than the normal between July to December was beneficial to crop and would help in enhancing the yield, whereas, excess RAIN beyond normal after December would reduce the yield of black pepper as it may affect maturity. Krishnamurthy *et al.* (2011) studied the correlation between monthly rainfall and productivity of black pepper brought out the adverse effect of December - January rainfall and favourable effect of April- May rainfall. The increase in RHMRN during the annual cycle of black pepper by 1% more than the average, the beneficial effect on yield was observed. The results showed that the beneficial effect on yield due to increase in the RHMRN was varied from 1.169 to 1.107 kg vine^{-1} during the lag period (March-May), 1.102 to 1.074 kg vine^{-1} during the spike emergence and flower bud differentiation stage

(June-July), 1.072 to 1.056 kg vine^{-1} during the spike enlargement and berry formation stage (August-October), 1.056 to 1.064 kg vine^{-1} during the berry development stage (November-December) and 1.066 to 1.088 kg vine^{-1} during the final maturity and harvesting stage (January-February) of black pepper. Similarly, RHAFN increase during the annual cycle of black pepper by 1% than the normal, the beneficial effect on yield was observed. The effect due to increase in the WIND above the normal was beneficial on yield during annual cycle of black pepper. The adverse effect of EPN on net change in black pepper yield (kg vine^{-1}) was observed due to increase by one unit (1mm) more than the normal, the reduction in yield was observed throughout the annual cycle of black pepper. The results showed that the adverse effect on yield during lag period period (March-May) was 0.043 kg vine^{-1} and decreased slightly up to 0.022 kg vine^{-1} during the spike emergence and flower bud differentiation stage (June-July). Further, the effect was maximum of 0.084 kg vine^{-1} during the maturity and harvesting stage (January-February) of black pepper. It may be, however, the beneficial effect on net change in yield kg vine^{-1} could be obtained only if the EPN was 1 mm less than the normal. The adverse effect of BSSH on net change in black pepper yield (kg vine^{-1}) was observed due to increase by one unit more than the normal, the reduction in yield was observed throughout the annual cycle of black pepper. Pradeepkumar *et al.* (1999) found a positive correlation with maximum temperature and number of sunshine hours in the first fortnight of March and has a negative correlation with the mean relative humidity during the July, sunshine hours received in February first fortnight and April second fortnight. Thus, if the distribution of weather variables is known, the yield trend can be estimated very well for different years. By using the regression equation obtained for effects of rainfall on black pepper yield, the predicted and actual yield for different years from 2012-13 to 2018-19 are shown in Fig.1. The figure clearly shows that the predicted yield is very close to the actual (R^2 = 0.90), only for two years the predicted yield was beyond the standard error value (Here, SE = 0.34).

It can be concluded that there is a significant relationship between weather variables and yield of black pepper during the annual cycle. The enhancement of temperature showed the adverse effect, while the climatic variables like RHMRN, RHAFN and WIND showed their beneficial effect on net change in black pepper yield. A second-degree multiple regression equation can profitably be employed in quantifying these relationships.

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