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ABSTARCT

The knowledge on the role of climate in crop production is essential precondition for sustainable agriculture and crop-weather analysis model (CWAM) helps to understand the crops association with weather. Black pepper is an important spice grown in rainfed under tropical humid and sub-tropical climate and the present study was undertaken to establish crop-weather relationship in black pepper by using second-degree polynomial equation. Readily available weekly meteorological data such as maximum temperature (°C) (TMAX) and minimum temperature (°C) (TMIN), maximum relative humidity (%) (RHMAX) and minimum relative humidity (%) (RHMIN), rainfall (mm) (RAIN), evaporation (mm) (EVPN), wind speed (WIND) (km h^{-1}) and bright sunshine hours (SUNS) data and black pepper fresh spike yield for six years (1992-93 to 1997-98) were used in this study. The association between black pepper yield and weather indicated that effects of change in weather variables in successive weeks were not an abrupt or erratic change but an orderly one. The regression models developed in this study 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. All the weather parameters studied had significant relationships with black pepper yield except RHMIN (R^2 = 0.4697) and EVPN (R^2 = 0.3913). Crop-weather relationships developed in this study provides information on the response of black pepper to weather and would help further studies in this direction particularly in the context of changing climate.

Key words: Black pepper, climate, crop-weather model, modeling, *Piper nigrum*.

INTRODUCTION

Crop productivity - both quantity (economic yield) and quality (colour, aroma, pungency etc.) are largely governed by weather and climate of a locality coupled with genotype, soil, and crop management and it is a result of complex interactions. Black pepper (*Piper nigrum* L.) belongs to family *Piperaceae* is unique crop owing to its pungency and aroma– popularly called 'King of spices' or 'Black Gold;' is a native of Western Ghat region of India, was one of the earliest commodities traded between the Orient and Europe. It is the most important spice traded internationally too. More than 25 countries near the Equator between 20° N and 20° S with tropical climate produce this crop and main producing countries are Vietnam, India, Indonesia, Brazil, Malaysia, China and Sri Lanka (Parthasarathy *et al*., 12). A wet tropical climate with a well-distributed rainfall of 2000 to 4000 mm per year with brief dry period, mean temperature of 25 to 30°C, and relative humidity of 65 to 95% are most suitable for pepper and it is weather dependent for its performance (de Waard, 2) and grows up to 2000 m MSL. The crop is cultivated as rain-fed and yield influenced considerably by environmental factors (Ridley, 18; Menon, 11; Pillai and Sasikumaran, 13; Suparman, 20; Pradeepkumar *et al*., 16). In most of the countries producing black pepper, the small holders's crop and more than one million farmers depend on it for their livelihood (UN, 21), even under favorable weather, a steady market and government support is required for stable production of this crop by small growers (Wadley and Mertz, 22). Crop takes three years to give its first yield, the first, second and third year yields are 500, 1000 and 3000 to 4000 g fresh berries per vine, respectively under normal weather and management (Kandiannan *et al*., 9). The yield increases gradually and attains stabilization after few years and it vary with cultivars, crop health and management (Pillay *et al*., 14). Inter-annul yield variations was mainly due to weather particularly quantum and distribution of rainfall (Ridley, 18; Menon, 11; Purseglove *et al*., 17; de Warrd, 2, Suparman, 20; Sivaraman *et al*., 19; John *et al*., 6).

The knowledge on the role of climate in crop production is an essential precondition for sustainable agriculture and this can be understood with help of crop-weather analysis model (CWAM). The CWAM is defined as the simplified functional relationship between a particular plant response (e.g. yield) and the variations in selected weather variables at different plant developmental stages (Baier, 1). Fisher (3) studied

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the gradual change of the effect of weather variables on crop yield development during the growing season with special statistical tool - 'orthogonal polynomial technique'. He assumed that the effects of change in weather variables in successive weeks would not be an abrupt or erratic change but an order one that follows some mathematical law. Several workers have studied the crop-weather relationship (CWR) by using Fisher's technique. Hendricks and Scholl (4) have modified the Fisher's method. They assumed that a second-degree polynomial in a week number was sufficiently flexible to express the relationship. The CWR of seasonal crops were studied with this tool. In this study, first time we have used this method for perennial horticultural crop - black pepper to find the association of weather inputs with annual yield.

MATERIALS AND METHODS

The readily accessible weather data of rainfall, maximum and minimum temperature and relative humidity, sunshine hours, wind speed and evaporation were collected from Agro-met. Observatory maintained at Agricultural Research Station at Ambalavayal, Wayanad district in Kerala. The Wayand district is a part of Western Ghat of India and it is one of the efficient black pepper producing zones having high relative spread and yield of black pepper (Kandiannan *et al*., 8). The maximum temperature (°C) (TMAX) and minimum temperature (°C) (TMIN) were collected using mercury and alcohol-in-glass thermometers placed inside Stevenson's screen. Maximum relative humidity (%) (RHMAX) and minimum relative humidity (%) (RHMIN) were obtained by transforming the current dry and wet bulb temperature using dry and wet bulb (mercury-in-glass) thermometers. Rainfall (mm) (RAIN) was recorded from ordinary (manual) rain gauge. Evaporation (mm) (EVPN) was observed from US weather Bureau class A pan evaporimeter (USWB A type). Wind speed at eight feet height (WIND) (km h^{-1}) read in Robinson cup anemometer. Sunshine hour (SUNS) was read from the sunshine recorder (Heliograph). Daily weather data for six years (1992-93 to 1997-98) have been obtained from the station and weekly mean for all variables were calculated except for rainfall for that weekly total has been worked out and used. The annual fresh spike yield of black pepper cultivar Panniyur 1 for the same period of that station was collected and crop-weather relationship has been worked out. Black pepper is a perennial crop, to mark the beginning and end of annual cycle, meteorological week 10th (5th-11th March) and subsequent year 9th (26th Feb-4th March), respectively are taken based on our experience. 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 period of the year. 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*. (5).

$$Y = A_0 + a_1 \sum_{i=1}^{n} t_i^0 X_i + a_2 \sum_{i=1}^{n} t_i^1 X_i + a_3 \sum_{i=1}^{n} t_i^2 X_i + DT$$

Where, Y = black pepper fresh spike yield (kg ha^{-1}); x_i = any climatic variable within any given seven day period; t_i = the number of each of seven day periods (it is 1 for the period from 5th - 11th March (10th Standard meteorological week) and 52 for the period from subsequent February 26th to 4th March(9th Standard meteorological week); n = 52 seven day periods in a given crop season; T = year number; A_0, a_1, a_2, a_3 and D = constants

RESULTS AND DISCUSSION

The weekly weather during black pepper annual cycle is given in Fig. 1a-h. 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-uly), 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. The 10th standard week (5th-11th March) was considered as beginning of the annual black pepper cycle and mean weekly RAIN at this week was 8.5 mm and it gradually attained maximum of 161.1mm during 28th week (9-15 July). Subsequently, it reached zero at the end of the annual cycle. The TMAX varies between 23.43° and 31.67°C during the cycle, at the beginning TMAX was above 30°C and reached the minimum of 23.43°C during end of July month, and this is the period monsoon activity is peak and spike emergence and enlargement is also high. After July, TMAX gradually increased until end of the cycle. The TMIN was 16.97°C at the beginning, and increased gradually reaching maximum (19.47°C) during April end, thereafter, dropped to 13.87°C during January first week and it increased in later part. The RHMAX during initial week was 87.1%, increased gradually upto April end (91.5%), dropped for two weeks and increased subsequently to 92.6% during 11–14th June, and maintained up to the end of October. Thereafter, declined to 79.7% towards the end of January and increased subsequently. The RHMIN range was 36.08 to 84.87 %, it was 37.43% at the beginning and increased gradually reaching maximum (84.87%) during 23-29 July. It declined towards end of the cycle reaching low value of 36.08% during January end and it increased gradually afterwards. The SUNS varied between 0.8 h per day during July end and 9.6 h during end of January. During first week of the cycle it was 9.5 h and it reduced to 5.9 h during middle of April and again increased during May, but it decreased again in June and reaching minimum in July, thereafter it gradually increased towards the end of the cycle. Mean weekly WIND varied between 1.8 and 5.7 km hr^1 during annual pepper cycle. At the beginning it was 3.7 km hr^{-1} and continued up to the end of May, then it increased up to middle of June, further, it deceased towards middle of September, again it increased with a peak during middle of October that continued up to the end of annual cycle. The mean weekly EVPN was around 5 mm and declines towards middle of the annual cycle and increased gradually up to end.

The regression model for different weather parameters with black pepper fresh spike yield (Table 1) has been brought out the magnitude of association *i.e.*, RHMAX > RAIN > TMIN > TMAX > SUNS > WIND > RHMIN > EVPN. The nature of association between weather elements during annual black pepper cycle and yield has been worked (Fig. 2 a-h). The effects of change in weather variables in successive weeks were not an abrupt or erratic change but an order one that follows some mathematical law (Fisher, 3). The maximum annual growth of black pepper *i.e.*, new flushes initiation and its growth, spike emergence and development coincides with the peak rainy period. Total rainfall and its distribution play an important role in black pepper production. An annual rainfall of around 2000 mm with uniform distribution is ideal. In India, black pepper growing areas receive annual rainfall of 1500 mm to more than 4000 mm (Sivaraman *et al.*, 19). Rainfall of 70 mm received in 20 days during May-June has been sufficient for triggering off flushing and flowering process in black pepper, but once the process is set off there should be continuous shower until fruit ripening. Any dry spell even for few days, within this critical period of 16 weeks (flowering to fruit ripening) would result in low yield (Pillay *et al.*, 15). The nature of relationship indicates that rainfall beyond normal during initial period of annual cycle (*i.e.*, 5^{th} -11^{th} March to 25^{th} June -1^{st} July) was harmful or would reduce the yield. Kannan *et al.* (7) noted that total of 244.5 mm rainfall was received in 26 days in March-April and 144.1 mm in 14 days during May resulted in very low yield, whereas, no rainfall in January-February and 40 mm in days March and good rainfall from third week of April-August resulted in good yield. Mathai (10) has observed that growth of fruit bearing lateral shoots (plagiotrophs) and photosynthetic rate were the maximum during peak monsoon in India (June-July). The rainfall excess than 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. Pradeepkumar *et al.* (16) reported that mean maximum temperature in March first fortnight and June second fortnight, total sunshine hours received during February first fortnight, March first fortnight and April second fortnight, total rainfall during March second fortnight and September second fortnight, mean maximum relative humidity during March first fortnight and mean minimum relative humidity during March second fortnight and July first fortnight were found to be significantly correlated with the pepper yield of succeeding year.

TMAX increase by one unit than the normal during first six weeks and last four weeks at the end of the annual cycle would favor the crop (Fig. 2b), whereas, such increase during end of April would affect the yield. In contrary to TMAX, TMIN increase favours the crop during major period of annual cycle (Fig. 2c). RHMAX increase during initial 12 weeks of annual cycle was beneficial and it was in the deceasing order. If RHMAX increases above the normal from June beginning it is harmful to crop and would reduce the yield (Fig. 2d). Probably, more RHMAX might bring disease that harms the crop. The effect due to increase in RHMIN during initial 11 weeks was negative (Fig. 2e). The effect was positive from June onwards up to end of October and the effect was negative subsequently towards end of the cycle, however, the effect was not significant ($R^2 = 0.4697$). The effect on yield due increase in sunshine above the mean during beginning of the cycle up to the end of October was harmful (Fig. 2f). The increase from November month to the end of the cycle was beneficial, as it helps to berry development and maturity. The effect due to increase in the wind speed above the mean during annual cycle was positive and significant throughout ($R^2 = 0.8039$) (Fig. 2g). However, the magnitude was high during beginning and end of the cycle. The beneficial effect was the minimum during August, September and October months. The effect of EVPN was positive but not significant ($R^2 = 0.3913$) (Fig. 2h). Crop-weather relationships are not so simple, the relations developed here provides the dependence of black pepper yield on weather, it is a first step would guide for more sophisticated approaches in this direction.

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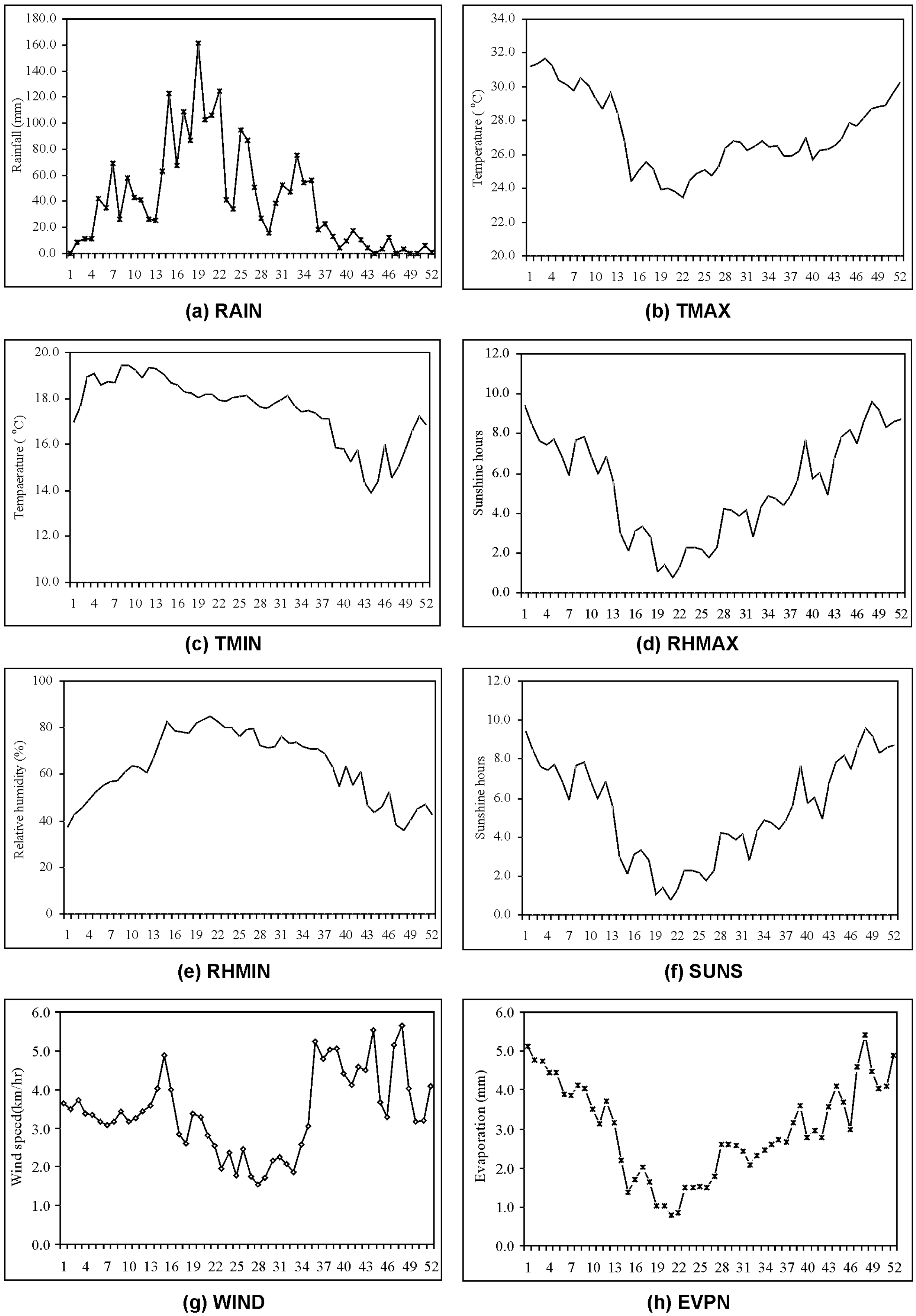

Fig. 1. a-h**,** Pattern of weather parameters during annual cycle of black pepper, 'x' axis is week numbers; 1 starts at10th Met week (5th–11th March) and 52 ends in 9th Met week (26th Feb to 4th March).

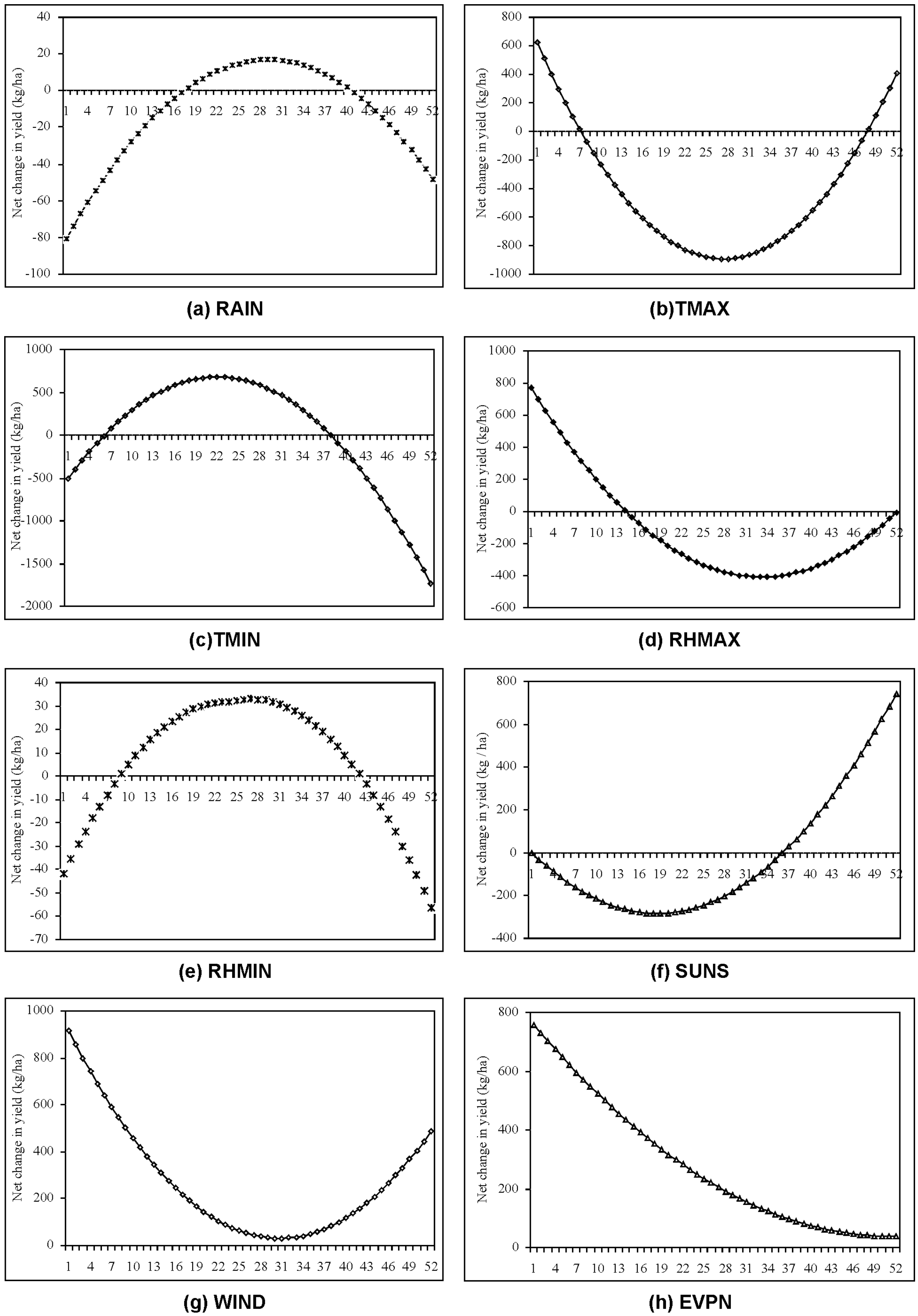

Fig. 2. Black pepper yield response to a unit change in weather parameters, a-h, are weather parameters during annual cycle of black pepper, 'x' axis is week numbers; 1 starts at10th Met week (5th-11th March) and 52 ends in 9th Met week (26th Feb to 4th March).

Table 1. Multiple regression equations for different weather parameters with their coefficient of determination.

Weather variable	A_0	a_1	a_2	a_3	D	R^2
RAIN	19251.28	-87.4723	+ 7.1875	- 0.1265	- 3270.60	0.9903*
TMAX	517916.5	+739.2907	- 118.896	+ 2.1645	+ 4660+41.0000	0.8951*
TMIN	-50547.1	- 620.4070	+ 118.332	- 2.6884	+ 1604.60	0.9549*
RHMAX	620023.4	+762.4049	- 71.5938	+ 1.0798	+ 3899.46	0.9904*
RHMIN	21039.36	-27.3050	+ 2.9649	- 0.0637	- 134.47	0.4697
SUNS	13647.90	+33.1306	- 34.0799	+ 0.9179	- 797.67	0.8564*
WIND	-50732.2	+974.3641	- 61.5596	+ 1.0036	+1236.57	0.8039*
EVPN	-37675.1	+786.7272	- 29.2401	+ 0.2858	- 895.22	0.3913

*Significant (P = 0.05)

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