MODELING HEAT STRESS EFFECT DURING FLOWERING AND EARLY FRUIT SET ON APPLE YIELD

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Abstract:

A simple agromet model was developed for assessing the effect of heat stress during flowering and early fruit set on Apple yields over the high elevation orchards of Balochistan Province of Pakistan. This model uses hygrothermal stress only and the stress was considered to occur when the daily maximum temperature rose higher than 35°C and relative humidity dropped below 30%. In addition to maximum temperature and Relative Humidity, the timing of occurrence in relation to flowering and early fruit set. The climatic data inputs are based on experimental results in temperature range above 35°C extrapolated linearly. A series of weighing factors were used for the duration of heat spells in days. In the temperature range 35°C to 37°C the weighing was n-1, for 37°C to 39°C range 1.4n; and for 39 to 45°C range, 2n. Weighing factors for the timing of occurrence of heat spells follow closely the near normal percentage distribution curve of open flowers. At bud burst in March, the weighing is 0.4, increasing to 1.3 at early fruit set by mid-May and decreasing rapidly to 0.3 by the end of June. The functional relationship between the model hydrothermal stress output and the yield of apple for an irrigated, high yielding plantation shows fairly good correlation r2=0.41 to 0.51, depending on the statistical method used. The agreement between hydrothermal stress index and the yield of apple is closely related only during those years when plantation is subject to hydrothermal stress index greater than 8.

Introduction:

The area under study is arid in nature and located at varied elevation generally 500m above mean sea level (Chaudhry et al; 2004). Temperatures drop several degrees below freezing point in winter and mercury touches 40 degree Celsius in summer. Relative humidity of the air in early summer is as low as 10% during daytime. Precipitation season spans January to March and makes an annual total 261 mm. Most of the precipitation occurs in the form of snow and rain during winter from December to March. Sometimes the snow episodes have been experienced even in November.

Apple is largely grown in Quetta and Kalat valleys and adjoining high elevation agricultural plain since long by irrigation from underground water. Underground aquifers were used by the farmers as Karazes which suffered from depletion and the most of them have dried out. Now the orchards and field crops are mainly grown under rainfed conditions. Under drought conditions the apple orchards suffer from water

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deficit seriously effecting the growth and yield. Generally availability of water is not the problem in winter season.

Temperature, on the other land, fluctuates considerably during flowering and fruit set. It is assumed that, in addition to physiological control mechanism, the temperature fluctuations in low atmospheric humidity conditions are responsible for the major part of variability in yields of apple.

Opinion varies regarding the negative effect of low temperatures during flowering and fruit set. However, there is considerable evidence for the detrimental effect of high temperature on flowering and fruit set. Sedgley and Annells (1981) reported those high temperatures of 35°c or more persisting up to 10 days after fertilization caused complete early fruit drop. It is suggested that high temperatures during flowering and fruit set are responsible for early abortion and low yields (Papademetriou 1976).

The flowering process is controlled by the interaction of the genetic plant material with environmental factors. The two climatic factors temperature and moisture contents of air play the most important role in controlling reproductive development.

This study was conducted to model the effect of high temperature during the day in low atmospheric moisture contents on apple yields. Some of the damaging high temperature values have been taken from the evidences and empirical values have been introduced for the duration and timing of heat spells. The resultant hygrothermal stress index obtained was correlated with 10 years of apple yield data for a plantation at Agromet Centre, Quetta. It was assumed that good correlations between a modeled hygrothermal stress index and fruit yield would indicate a cause and effect relationship and permit the quantitative assessment of the effect of extreme temperatures and low humidity on flowering and early fruit set. The successful application of such a model, which is a simplified representation of a complex relationship, can provide a useful tool for assessing the long term yield potential and variability of areas to be planted. It can also be used for irrigation practices aimed at micro climatic modification, in order to reduce damage to yield due to hygrothermal stress.

Materials and Methods:

In developing a hygrothermal stress model, the following temperature and humidity components were taken into account:

(a) The daily maximum temperature > 35°C along with relative humidity <30%;

(b) The duration of such hygrothermal stress; and

(c) The timing of such spells in relation to flowering and early fruit set.

The hygrothermal stress index was the weighted production of three components.

Maximum Temperature Threshold Values:

The effect of maximum temperature during flowering and fruit set of apple is based upon the research work of many researchers. The critical maximum temperature is determined as 35°C. Higher temperatures were considered to have negative effect due to a detrimental impact on the fertilization process and the degree of pollen sterility. Maximum temperature > 42°C were considered to be the catastrophic events for apple fruit yields.

Duration of Heat Wave:

The duration of heat wave considered to be the number of days that the temperature was > 35°C and relate humidity remained below 30%. It was considered that longer the duration of heat wave, the more harmful it would be to the reproductive process. Dry atmosphere, high temperatures and their longer persistence can affect inflorescence sterility.

A negative effect of the duration of stress has been demonstrated for annual crops by Shaw (1974) as well as Lomas and Herrera (1985), although their work is on moisture stress. Lomas and Shashoua (1974), however, clearly showed that the longer the period of hot and dry days, the lower the wheat yields. Field observations also confirmed this fact, although the quantitative value of the effect of the duration of heat wave on apple yield is not known. Therefore, a series of empirical weights were proposed for trail analysis by computer, increasing in value exponentially. The finally selected weights hold the highest correlations with yield. Thus, for temperature range 35°C to 37°C, the relative weighing factor for spell duration was n-l for 37°C to 40°C range, 1.5n; and for the 40°C to 45°C range, 2n.

Effect of Hygrothermal Stress Timing:

Apples begin flowering in Quetta during March and complete the flowering process in April. The duration of flowering period is temperature-dependent (Levin 1981; Lomas and Shashoua 1983).In Quetta valley it lasts for 30 to 35 days.

The percentage distribution of open flowers of the inflorescence over time follows a near-normal distribution curve. The curve peaks some days after the half way mark of the duration period of the flowering process. Since the beginning of the flowering process starts relatively slowly due to low temperatures early in the season. Levin (1981) showed that the earlier the bud burst and the lower the temperature, the longer the duration of flowering process. Similar results were reported by Lomas and Burd (1983) for citrus.

Database:

The crop yield (T/Ha) was obtained from a plantation of 0.8ha in the premises of Geophysical Centre in Quetta valley. Detailed records of 10 years (1980-89) were available. Yield variability from year to year was considerable; Coefficient of Variance (CV) is 38 %. Phenological data collected at agrometeorological experimental field at Geophysical Centre Quetta were used in developing the model. Moreover meteorological data for the same period at the same site had also been documented. Homogeneity of data is critical in a long term agroclimatic analysis as stated by Lomas and Herrera (1985) and the plantation of Geophysical Centre Quetta fulfills this requirement. Exposoure, operation and maintenance of the recording and non-recording instruments were up to the mark to generate quality data.

Conceptual Agrometeorological Model:

The climatic data-driven agrometeorological model consists of the calculated hygrothermal stress index (I). This index is based on the three components: the daily maximum temperature, duration of hygrothermal stress spells, and their timings in relation to phenology of flowering process in apple. Both quadratic and cubic regressions were used. This took the form of

$$Y = a + bI + cI2 \quad (1)$$

$$Y = a + bI + c\ I2 + dI3 \quad (2)$$

Where,

Y = The expected yield of apple and
I = The weighted hygrothermal stress Index.

Apple producers claimed that the possible effect of heat spells during, flowering and early fruit set was, to some extent, predetermined by winter temperatures preceding the flowering period. Peak winter (December to February) mean minimum temperatures therefore were included in the analysis as additional variable. Having obtained the response of the apple yield to the index (1), the mean minimum temperature was included in a multiple regression of the form:

$$Y = a + bI - C\ I2 + dT - eT\ 2 \quad (3)$$

Where,

Y = Expected yield of Apple,
I = Weighted hygrothermal stress Index; and
T = Mean minimum temperature (December to February).

The objective of the model was to provide numerical relationship between excessively high temperatures in low air humidity during flowering and early fruit set period and yield of the apple.

Results and Discussion:

The climate of Quetta valley and its adjoining plains, famous for apple production, is arid in nature. The spring season (March to May) is a period with considerable climate variability. At the end of rainy season and the beginning of the dry season, changes in local synoptic circulation are responsible for the relatively large fluctuations in temperature and relative humidity. Rasul (1999) conducted a study on stress conditions under rainfed cultivation over Punjab Plains in Pakistan. He found that moderate stress conditions start to occur when daytime maximum temperature reaches 35°C combined with mean daily relative humidity less than 30%. Similarly severe stress day claimed at 40°C or more with mean daily relative humidity less than 30%. He also pointed out that persistence of hygrothermal stress conditions in spring have adverse effects on pollination and fruit set on mango plants. The area under present study is although comprised upon an arid high elevation plateau where frequency of 40s Celsius is less but crop environment is extremely dry when westerly winds prevail in spring. The average climatic data for Quetta which represent high elevation agricultural plains are presented in Table-I.

Table-1: Average Climatic Conditions (PMD, 1991) for Quetta Valley

Month	Rainfall (mm)	Temperature (°C)		Photoperiod (hrs)	Radiation (J/m2)
		Maximum	Minimum		
January	56.7	10.8	-3.4	221.6	11.97
February	49.0	12.9	-0.9	208.5	14.32
March	55.0	18.7	3.4	232.6	16.98
April	28.3	24.8	8.3	272.5	20.92
May	06.0	30.4	11.5	334.2	24.41
June	01.1	35.3	15.9	325.6	26.31
July	12.7	35.9	19.9	313.5	25.16
August	12.1	34.8	17.9	312.5	24.09
September	00.3	31.4	10.9	294.4	22.47
October	03.9	25.5	3.8	307.2	19.73
November	05.3	19.2	-0.9	278.2	16.25
December	30.5	13.3	-3.2	238.7	11.98

The simultaneous occurrences of high temperatures and low relative humidities are highly correlated. Winter rains sometimes continue to persist till early March which reduces the risk of stress conditions. During the month of March this correlation was r2=0.48, increasing gradually to r2=0.79 in June. The frequency distribution of both maximum temperatures and the minimum relative humidity at Quetta are shown in Fig-I. Extreme conditions of both high temperatures (> 35°C) and low relative humidities (10 %) are fortunately not very frequent. Such conditions generally occur in an isolated way during May and June but not in continued spells. However, the frequency of 20% humidity averaged over a day along with day temperatures soaring above 35°C is quite high over the plateau orchards.

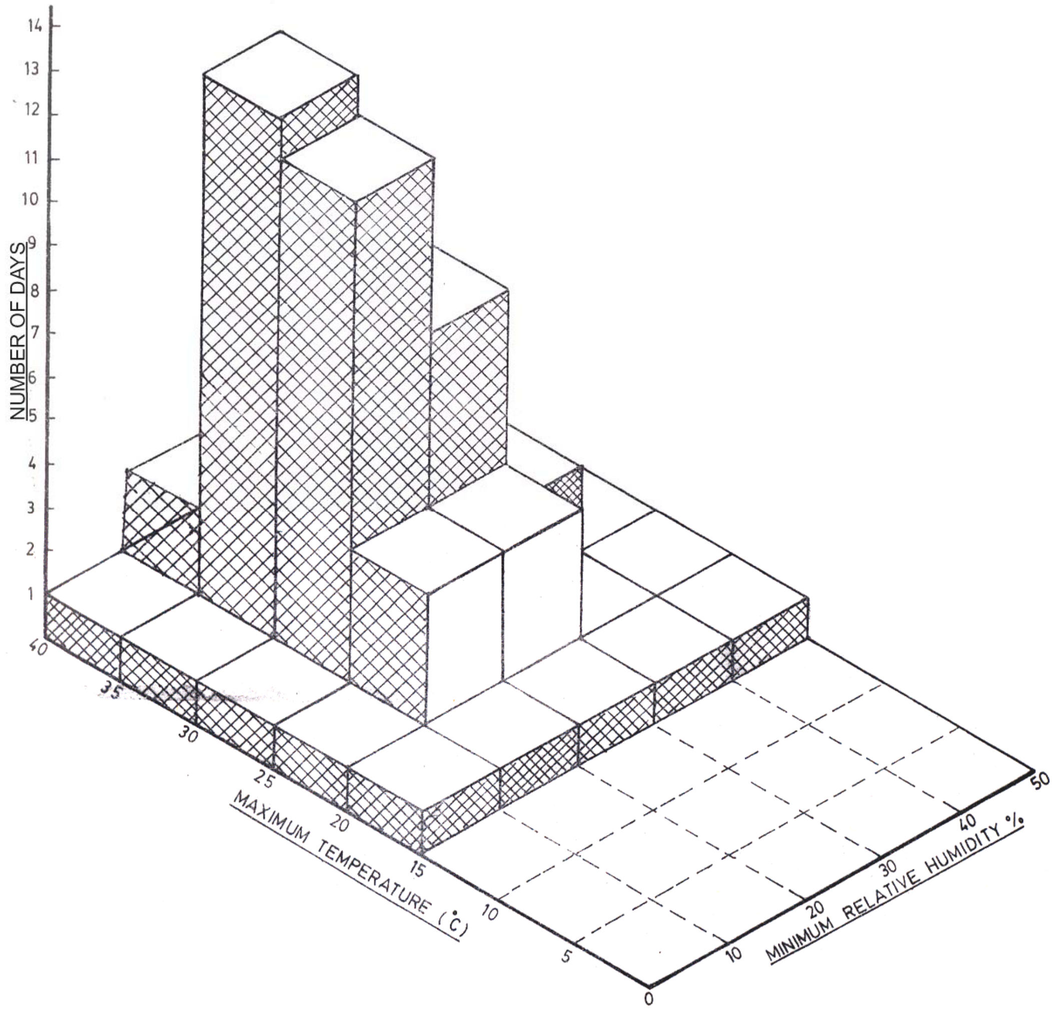

Figure 1: Frequency Distribution of Maximum temperature and Minimum relative humidity (lowest humidity observed at one of the three daily observations) at Quetta valley during April-May (1980-1989)

The agrometeorological model described is basically a simulation model using deterministic data. The specifications of the threshold values of maximum daily temperature of model are based on observational fact. In spite of the fact that the mechanisms through which temperatures affect inflorescence development are unclear, it was observed that temperatures > 35°c for several hours adversely affected the viability of mature pollen. Pollen exposed to higher temperatures lost its capacity to reach the embryo sac. That is why the temperature threshold 35°C was chosen.

In an effort to account for the negative effect of (a) increasing higher temperatures, (b) the duration of high temperatures, and (c) the timing of high temperatures in relation to the percentage open flower distribution and the period of early fruit set, an empirical procedure was adopted. The logical justification for the empirical values chosen is based on the fact that the functional relationship between the calculated hygrothermal stress index (I) and apple yields over a period of 10 years shows fairly good agreement.

The correlation between calculated I and apple yield is r2=0.59. The numerical relationship is presented in Figure-2. There were no significant differences between the quadratic and cubic relationship, except during years with little hygrothermal stress. The hygrothermal stress index (I) and apple yield was closely related in those years when plantation was subject to hygrothermal stress index > 8.

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