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INVESTIGATION ON THE PHYSICAL PARAMETERS OF ENVIRONMENT AND THEIR IMPACT ON COTTON CROP PRODUCTION IN THE SOUTHERN PUNJAB, PAKISTAN

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Abstract: Some physical parameters of the environment and their influence on cotton crop production were studied at Central Cotton Research Institute, Multan (30^0 12′N,71^0 28′ E, alt.123m). The results showed that highest rain expectation will be during the month of July and August considering 99 percent confidence intervals for a 10-year mean rainfall. This gives a strong support to the standard recommendation of ending the sowing of cotton by first weak of June to avoid re-planting of crop. The modified constants of Penman provide best estimates for potential evapotranspiration, total incoming short wave radiation and net solar radiation. The potential evapotranspiration (E_t) is an important component of environment to calculate crop evaportranspiration (ET) to measure crop water use at the location.

Keywords: Potential evapotranspiration, solar radiation, cotton crop, Penmann original formula, Penmann modified formula.

INTRODUCTION

Crop growth and development, pest infestation and field operations are highly weather dependent. Adverse weather can reduce crop yields, fibre quality and increase production cost [Zhang *et al.* 1994]. To ensure maximum yields and profits, it is desirable to attain completion of planting of cotton crop by a reasonable target date through judicious crop husbandry practices. Yield losses occur due to delayed planting of cotton crop with concurrent heavy damage caused by bollworms during later stages of growth and adverse weather conditions at the time of harvest of crop [Ahmad 2001]. Agrometeorology has become an important field in applied crop production research. The physical parameters of the environment acting individually or in combination influence the major processes associated with production [Taha *et al.* 1980].

The climate of Pakistan is influenced by the development of low pressure over the Indus plain at the beginning of summer and the position of the inter-tropical front, which forms at the head of the Bay of Bengal. Two air masses are attracted to this low-pressure area from both the Indian Ocean and the Arabian Sea and cause the main summer monsoon rainfall. Total rainfall during this period decreases from 1613 mm in the north to 323 mm or less in the south. During winter, winds blow from north-east to south-west and cause a small amount of rain, which increases northwards to westwards [Taha 1982].

Although almost all the cotton area in Pakistan is artificially irrigated, the amount and distribution of rainfall influences crop production in many ways. Excessive or light precipitation in early season frequently causes high mortality of crops at the seeding stage, resulting in an appreciable loss of plant stand and subsequent reduction of yield. This may be a frequent danger in areas with high rainfall but may occur in areas with lower average annual rainfall, where, due to bad distribution, five times as much as the annual average, may fall in one or two showers. Multan with an average annual rainfall of 11.4 mm, received about 59.3 mm in the month of July during the 1999 season (Table 1).

Table 1: 10-Year Meteorological Data on Rainfall (mm) Recorded at Central Cotton Research Institute, Multan (30° 12′ N, 71° 28′ E, Alt. 123m.)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0.5	2.2	0.8	36.0	7.9	1.5	5.2	0.7	24.0	0.0	0.0	4.4
1992	26.1	12.0	1.7	24.3	9.8	1.5	18.4	103.7	150.7	0.0	10.0	0.0
1993	10.0	1.3	15.2	37.3	24.8	8.0	208.2	0.0	4.7	0.0	0.0	0.0
1994	7.0	8.1	2.2	3.5	20.0	20.0	54.3	63.5	119.9	0.0	0.0	6.9
1995	1.3	2.9	17.0	74.5	20.0	8.6	37.1	86.0	6.8	0.0	0.0	1.5
1996	9.8	11.7	3.7	7.3	43.7	29.7	28.2	5.8	0.0	0.6	0.0	0.0
1997	5.5	0.4	27.1	5.0	19.9	31.8	73.0	1.6	0.0	142.4	3.9	2.0
1998	1.8	23.7	9.8	5.9	5.0	19.4	31.5	22.5	1.8	6.5	0.0	0.0
1999	13.8	38.0	5.5	0.0	0.0	0.0	59.3	2.4	14.9	0.0	0.0	0.0
2000	12.0	24.0	0.0	0.0	0.0	0.0	23.1	6.6	3.7	0.0	0.0	19.6
Av.	8.78	12.43	8.3	20.1	13.1	12.1	53.83	29.28	32.65	14.95	1.39	3.44
SD	7.6	12.5	8.9	23.7	14.1	12.3	58.0	39.7	55.1	44.8	3.3	6.1
SE±	2.4	3.9	2.8	7.5	4.5	3.9	18.3	12.6	17.4	14.2	1.0	1.9
LL	0.9	-0.4	-0.9	-4.3	-1.4	-0.6	-5.7	-11.5	-24.0	-31.1	-2.0	-2.9
UL	16.6	25.2	17.5	44.4	27.6	24.7	113.4	70.1	89.3	61.0	4.7	9.8

t value 1% = 3.25, SD = standard deviation, SE = standard error, LL = lower limit, UL = upper limit

Rainfall during flowering may reduce boll set and increase the number of unfertilized ovules in those bolls, which do not set mainly due to the sensitivity of pollen grains to moisture [Stewart 1980]. An indirect effect of increased rainfall is the resultant increase in relative humidity which favors the multiplication of certain insect pests viz; Jassid, Heliothis sp., pink bollworm and spotted bollworm [Ahmad 1995] and appearance of bacterial blight and leaf spot of cotton diseases [Hussain and Ali 1975]. Photoperiod also affects diapausing behavior of pink bollworm [Ahmad 1995]. It is important to plan operations so as to avoid peak rainfall occurrence during the sensitive stages of growth [Stern *et al.* 1982].
Keeping this view in mind, agrometeorological studies were undertaken to understand basics of components of the radiation balance, which affects the two important processes of evapotranspiration and photosynthesis and probability of rainfall at Multan.

MATERIALS AND METHODS

The investigations were undertaken at Agro-Meteorological Station, Central Cotton Research Institute, Multan. This location is situated at 30° 12' N, 71° 28' E, alt. 123m. The station is laid out according to standard procedures (FAO Irrigation and Drainage Paper No.24) in the centre of the experimental area. Except for a short part of the season (April-May), the station is usually surrounded by cotton crop.

Measurements on rainfall, temperatures, solar radiation, potential evaporation were recorded by using standard 5" raingauge, maximum and minimum thermometers contained in standard Stephenson Screen; Bimetallic Actinograph; United States Weather Bureau Class-A Evaporation Pan, Campbell-Stokes Sunshine Recorder and Anemometer.

Five methods were compared for the estimation of potential evapotranspiration, these are:

a) Using class A evaporation pan records and appropriate constants which take into account climate and pan environment [Doorenbos and Pruitt 1977].

b) **Penman Original Formula** [Penman 1948]:

RADIATION TERM: Shortwave; Outgoing Longwave — Aerodynamic Term

$$\frac{\Delta[(1-r)\,Rs\text{-}OTK^4\,(0.56-0.09\,1_d)\,(0.1+0.9\,n/N] + y[0.35(1_a-1_d)(1.0U_2/100]}{\Delta + y}$$

r	=	Reflection Coefficient of water = 0.05
Rs	=	Incoming shortwave radiation estimated from $Rs = (0.18 + 0.55\,n/N)\,Ra$, Where Ra is the extra-terrestrial radiation
n/N	=	Ratio of actual to maximum sunshine duration
1_d	=	Vapour pressure
1_a	=	Saturation Vapour Pressure
U_2	=	Wind speed at 2 m
T	=	Mean air temperature K^4
O	=	Stejan Blizman constant
Δ	=	Rate of change of saturation pressure with temperature
y	=	Psychorometric constant

c) Penman modified formula [Penman 1956]**:**

$$\frac{C[\Delta\,(1-r)\,Rs\text{-}OTK^4\,(0.34-0.044\,ed)\,(0.1-0.9\,n/N)] + y\,0.27\,(e_a-1_d)\,(0.1-0.9\,n/N)]}{\Delta + y}$$

n	=	Reflection coefficient for a green crop = 0.25
Rs	=	Incoming short-wave radiation estimated from $Rs = (0.25 + 0.50\,n/N)\,Ra$
C	=	Adjustment factor for day & night weather condition

All other symbols are the same as in b) above.

d) Using directly measured incoming solar radiation by the Bimetallic Actinograph and constants for calculating outgoing longwave radiation as in b) above.

e) As d) but using constants in c) for the calculation of longwave radiation.

Total solar radiation was estimated from the duration of sunshine hours using the relationship expressed by the Angstrom equation:

$$Rs = (a + b\ n/N)\ Ra$$

Where Rs is the total shortwave radiation, Ra is radiation at the top of the atmosphere, n/N is the ratio of actual to maximum sunshine duration and a & b are constants. In the absence of the locally verified constants, values of a = 0.25 and b= 0.50, from similar latitudes were used to calculate total solar radiation at Multan [Doorenbos, and Pruitt 1977].

Net solar radiation was obtained from $Rn = Rs - R_n l$

Where Rs is total incoming shortwave radiation corrected for the reflecting surface. In Penman's original Rs was corrected by the reflection co-efficient of water, 0.05 and the modified Penman by the reflection co-efficient of crop surfaces of 0.25. $R_n l$ is the difference between the amounts radiated back by the earth to the atmosphere and down coming longwave atmospheric radiation.

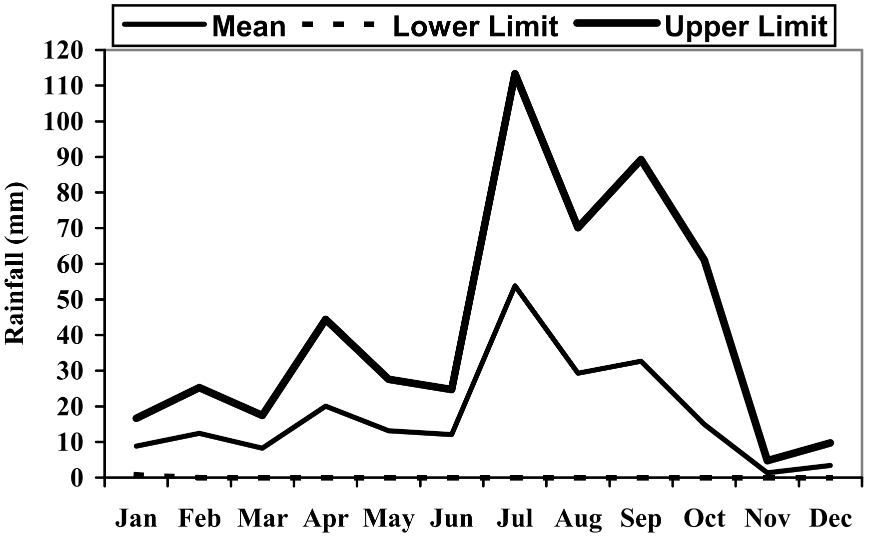

Fig. 1: The 99 percent confidence limits for average rainfall (1991-2000) at Multan.

RESULTS AND DISCUSSION

RAINFALL

Knowledge of the probability of the upper and lower confidence limits within which the mean rainfall for any particular period will occur is essential if disasters in crop production are to be avoided. Fig. 1 shows the 99 percent confidence intervals for a 10-year (1991-2000) mean rainfall at Multan. It is clear that the highest rain expectation will be during the month of July and August. Presently, the optimum sowing period of commercial cotton varieties for Multan, Bahawalpur, D.G. Khan is from 1st May to 10th of June and for Faisalabad and Lahore Division from 1st May to end of May. The cotton breeders have succeded in evolving a number of cotton varieties, which show tolerance to high night and day temperatures prevailing during reproductive development of plant. The planting of these heat-tolerant cotton varieties in vogue do not coincide the peak rainfall occurrence during planting season. The confidence intervals of the means used here is rather different from the confidence limits concept [Manning 1956], which is more appropriate for rain production and gives the probability of expecting a certain limit of rainfall necessary for germination or peak water consumption.

Progressive water management based on crop water use should take into account the amount of water stored in the soil profiles as a result of winter rainfall and the pre-sowing irrigation or heavy rainfall during the growing season.

POTENTIAL EVAPOTRANSPIRATION

The actual water used by crops varies greatly between seasons and locations depending mainly on the evaporative conditions of the atmosphere and crop characteristics determining ground cover and the roughness of the canopy. Plant water use can be measured directly by gravimetric method and indirectly by estimating crop evapotranspiration E_t. The results of estimation of potential evapotranspiration at Multan are plotted in Fig. 2. The main differences between the original Penman [1948] equation and the modified one [1956] is that the former refers to evaporation from an open water surface (Eo) and uses a reflection co-efficient r = 0.05 for water, other constants used in the equation are also slightly different from those used in the modified equation. The modified equation refers to evapotranspiration from green short grass, actively growing, completely covering the ground and well supplied with water (E_t) It uses a reflection co-efficient r =0.25 for crops, and different constants for estimating short wave radiation, outgoing longwave radiation and aerodynamic term. It also involves the use of an adjustment factor for day and night weather conditions. The methods using direct readings for estimating total shortwave radiation measured on the Bimetallic Actinograph gave low values of potential evapotranspiration through the season. Combining actinograph readings with Penman original constants for estimating outgoing longwave radiation gave the lowest estimate of potential evapotranspiration. The other three methods, pan estimate, Penman original and modified gave different values during April, May and June but agreed closely after the beginning of July. During these months hot dry winds commonly known as ‘Loo’ blow from southwest to north-west, temperatures are the highest and humidities are lowest. These conditions are conducive of advective energy transfer, which will affect evaporation from the US Class-A Pan more directly than other methods.

A marked reduction in potential evaportanspiration occurred from the beginning of July in response to the onset of the monsoons, which continues until the end of September; during this period E_t was depressed because of high humidities and the consequent low vapour pressure deficit. These conditions became less conducive to the horizontal transfer of energy and the agreement between the three methods became closer.

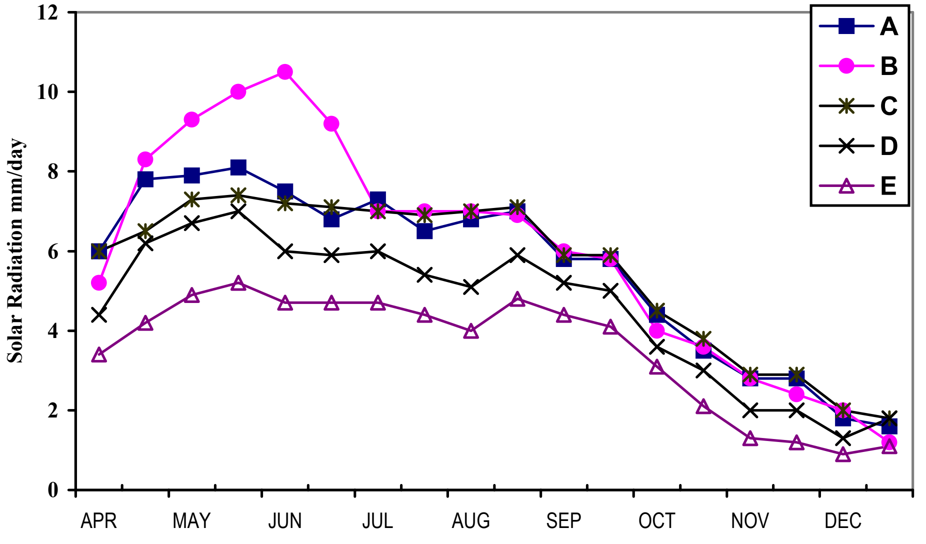

Fig. 2: Estimation of Potential Evapotranspiration Using Different Methods, **A** = Modified Constants, **B** = Penman's Original Constants, **C** = Pan Evaporation, **D** = Actinograph Reading and Modified Constants, **E** = Actinograph Reading and Penman's Constants.

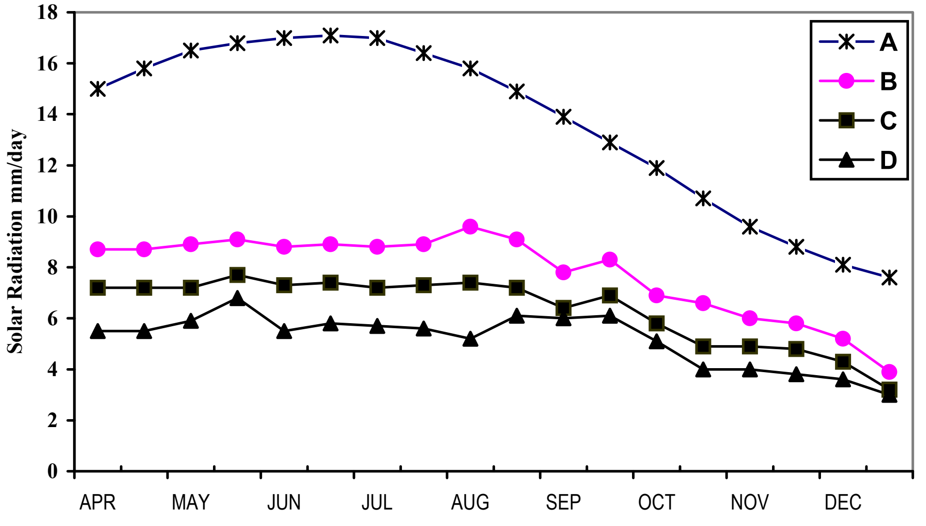

Fig. 3: Estimation of total solar radiation (RS) at Multan using different methods;
A = Extra Terretrial Latitude 30° N, **B** = Penman's Original, **C** = Penman's Modified,
D = Actinograph

SEASONAL TRENDS IN TOTAL INCOMING SHORTWAVE RADIATION

The total solar radiation recorded at Multan by using various methods are given in Fig. 3. The different methods gave different estimates but the seasonal trend is fairly consistent. The Bimetallic Actinograph gave the lowest estimate while the Penman original equation gave the highest estimates. The values of incoming short wave radiation were almost constant from April upto end of August. Thereafter, there was a progressive decrease in total solar radiation. These changes are associated with changes in the amount of radiation received at the top of the atmosphere. The increased difference between the extra-terrestrial radiation and the radiation reaching the surface of the earth during April to August might be due to the increased amount of dust in the atmosphere over Multan during the summer months and increased cloud cover during the monsoon months.

SEASONAL CHANGES IN NET SOLAR RADIATION

Data on net solar radiation at Multan are plotted in Fig. 4. The estimates of net solar radiation vary in the same manner as estimates of total radiation. The values are much more reduced compared to those of total radiation on account of the outgoing longwave radiation. Net solar radiation is the most important source of energy for the processes of evapotranspiration and photosynthesis and for heating the air and soil. The most important point brought out by Fig. 4 is the steady decrease of net solar radiation from the beginning of September onwards augmenting

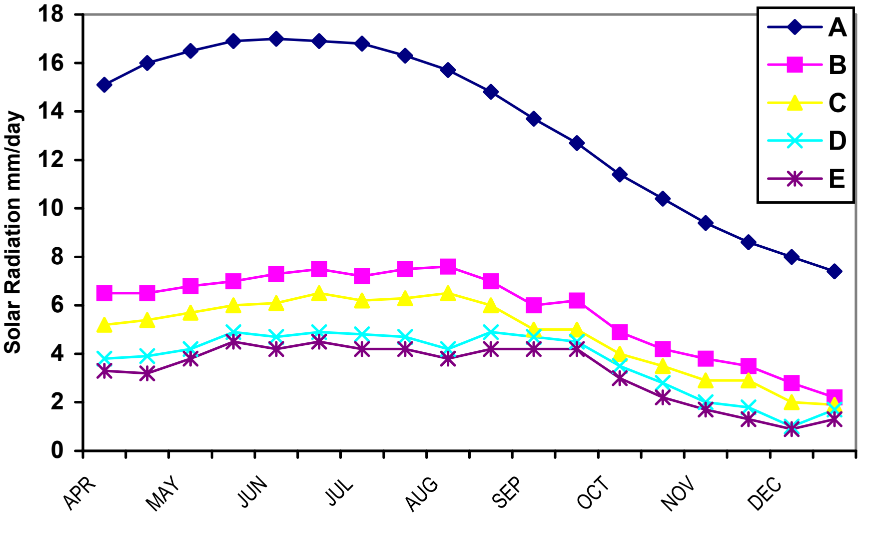

Fig. 4: Estimation of Total Solar Radiation (RS) at Multan Using Different Methods; **A** = Extra Terretrial Latitude 30º N, **B**= Penman's Original Constant, **C** = Modified Constant (a) **D** = Actinograph and (a) for Longwave, **E =** Actinograph and Penman for Longwave

the deteriorating conditions for growth and development. At this time of the season, cotton crop is already in the boll setting stages, therefore, the steady drop in temperature induces increased boll load, which results in high crop production.

References

Ahmad, Z. (**1995**) "25 Years of Research Activities (1970-1995) at Central Cotton Research Institute, Multan", pp. 1-101.

Ahmad, Z. (**2001**) Annual Progress Report for the year 2000-2001, Central Cotton Research Institute, Multan, pp. 1-137.

Doorenbos, J. and Pruitt, W.O. (**1977**) "Crop water requirements", *FAO Irrigation and Drainage*, Paper No.24.

Hussain, T. and Ali, M. (**1975**) "A review of cotton diseases of Pakistan". *The Pak. Cottons*, 19, 71-86.

Manning, H.L. (**1956**) "The statistical assessment of rainfall probability and its application in Uganda agriculture", *Proc. Royl. Soc. Lond.,* B 144, 460-480.

Penman, H.L (**1948**) "Natural evaporation from open water, bare soil and grass", *Proc. Roy. Soc. Lond.,* A 193, 120-146.

Penman, H.L.(**1956**) "Evaporation, an introductory survey", *Neth. J. Agric. Sci.*, 4, 9-29.

Stern, R.D., Dennett, M.D. and Dale, I.C. (**1982**) "Analysing daily rainfall measurements to give agronomically useful results. II A. modelling approach", *Exptl. Agri.*,18, 237-253.

Stewart, J.M. (**1980**) "Integrated development events and their response to environment in cotton bolls", *Proc. Beltwide Cotton Res. Conf.* National Cotton Council of America, Memphis, TN, USA, 322-340.

Taha, M.A. (**1982**) "Cotton Physiology" FAO Terminal Report, Pak/73/026, Central Cotton Research Institute, Multan, pp. 1-132.

Taha, M.A., Chaudhry, F.I. and Makhdum, M.I. (**1980**) "The influence of high temperature on the crop production pattern and fruit retention of three conventional cotton varieties (Gossypium hirsutum L.) in Pakistan", *The Pakistan Cottons*, 24, 19-36.

Zhang, J.P., Cochran, M.J., Tugwell, N.P., Bourland, F.M., Oosterhuis, D.M. and Danforth, D.M. (**1994**) "Using long-term weather patterns for targeting cotton harvest completion" *Proc. Beltwide Cotton Conf.* National Cotton Council, Memphis, TN, USA, 1284-1285.