551.586 : 633.11

STUDY ON CONSUMPTIVE WATER USE, HEAT UNIT AND RADIATION REQUIREMENT AND THEIR INFLUENCE ON YIELD OF WHEAT IN NEW DELHI

1. Wheat is an important staple cereal crop of the world. In India, it is the most important irrigated crop during the winter season in the semi arid region with mild winters and adequate seasonal and/or preseasonal rainfall. Cool weather during vegetative development and warm weather for maturity are deemed ideal for wheat. However, the condition of photoperiod, radiation, temperature extremes, rainfall and humidity plays a dominant role in growth and development and year to year variability in yield of the crop. The crop yield generally depends on several factors, for example: altitude/agroclimatic zones, soil type, crop variety, cropping system etc. The crop yields could be estimated through agrometeorological techniques using current weather data. Temperature is the primary driving force in crop development while radiation is the primary driving force in the growth of a crop, particularly for rabi-winter crops. The biochemical process leading to growth of plant and chlorophyll formation are intimately connected with the amount of radiation received. So, temperature and radiation have important role for proper growth/development and final yield of the crop in addition to favourable moisture availability. WMO (1982) published a compilation of statistical relationships between yield and agrometeorological factors for some important crops. All these relationships appear to be crop and region specific. In climatological models yields are related to randomly identified location specific climatic and soil factors (Das, 1971; Rupakumar and Subramanayam, 1986; Gupta and Singh, 1988; Shanker and Gupta, 1988; Rao and Vijayalakshmi, 1996).

TABLE 1

Agrometeorological variables required at various phenophases of wheat (variety Sonalika, HD-2009 and HD-2285)

Variety	Year	GDD				PAR				ET			
		P_1	P_2	P_3	Total	P_1	P_2	P_3	Total	P_1	P_2	P_3	Total
Sonalika	1976-77	406.4	340.5	780.0	1526.9	137.8	115.6	163.40	416.8	95.2	170.6	259.8	525.6
	1977-78	528.8	410.1	711.4	1650.3	155.9	125.9	166.10	447.9	119.7	174.5	219.1	513.3
	1978-79	586.1	432.0	901.7	1919.8	160.4	132.0	195.00	487.4	102.8	125.2	41.3	269.3
	1979-80	518.7	360.5	900.9	1780.1	145.4	134.3	183.40	463.1	70.2	129.2	185.3	384.7
	1980-81	477.6	450.8	790.2	1718.6	131.9	123.6	162.00	416.9	69.1	164.9	53.5	287.5
	1981-82	506.8	380.3	686.0	1573.1	146.2	107.2	161.30	414.7	151.2	156.4	51.8	359.4
HD-2009	1982-83	570.0	513.3	836.4	1919.7	165.6	141.5	184.2	491.3	92.0	161.1	122.4	375.5
	1983-84	524.4	493.4	804.6	1822.4	159.9	142.1	188.8	490.8	111.2	168.4	102.4	382.0
	1984-85	549.4	391.6	811.5	1752.5	142.4	135.9	179.9	458.2	146.2	166.2	105.5	417.9
HD-2285	1985-86	526.3	401.0	830.4	1757.7	151.3	91.9	186.50	429.7	105.5	164.5	67.2	337.2
	1987-88	473.8	433.9	801.1	1708.8	121.9	113.4	180.00	415.3	97.2	176.2	105.3	378.7
	1988-89	576.5	492.2	946.9	2015.6	140.2	142.3	201.90	484.4	104.4	162.8	95.9	363.1
	1989-90	498.8	450.0	933.9	1882.7	123.2	115.2	177.90	416.3	109.7	171.9	108.4	390.0
	1990-91	511.1	505.1	903.9	1920.1	148.4	126.3	190.40	465.1	73.0	125.3	72.1	270.4
	1992-93	519.8	461.0	748.8	1729.6	134.5	107.9	166.80	409.2	87.3	157.9	88.2	333.4
	1994	553.6	553.1	1062.2	2168.9	147.8	170.3	199.70	517.8	63.7	101.1	23.1	187.9
	1997	474.2	544.6	730.8	1749.6	154.6	119.9	142.2	416.7	128.8	160.3	116.9	406.0
	Mean	517.78	447.85	834.16	1799.79	145.14	126.19	178.20	449.54	101.6	155.09	106.95	363.64
	Std. Dev.	44.54	62.84	97.11	159.76	12.73	18.03	15.90	35.31	25.44	21.40	62.73	83.33
	C.V. (%)	8.60	14.0	11.64	8.88	8.77	14.29	8.92	7.85	25.04	13.80	58.65	22.92

P_1 – Sowing to tillering, P_2– Ear emergence to flowering, P_3 - Grain formation to harvest maturity

The importance of the present study is to know the dependance of wheat yield on some agrometeorological variables and an attempt has been made here to examine the year to year variability in consumptive water use (ET), growing degree days (GDD) or heat unit and photosynthetically active radiation (PAR) during growing season of wheat crop for variety Sonalika, HD-2009 and HD-2285 in New Delhi. Attempt has also been made to quantify the response of phenophasewise growing degree days (GDD), photosynthetically active radiation (PAR) and evapotranspiration (ET) on grain yield and to predict the final grain yield of wheat crop in New Delhi.

2. The study pertains to New Delhi observatory (location, Lat. 28° 40' N, Long. 77° 10' E, 228 m.a.s.l.). The evapotranspiration (ET), yield and phenological information of wheat crop for the variety Sonalika (1976-82), HD-2009 (1982-85) and HD-2285 (1985-97) for New Delhi observatory were collected from India Meteorological Department, Pune. The ET data were measured through gravimetric lysimeter located in the crop field. Daily data on maximum/minimum temperature and bright sunshine hours needed for computing the GDD and PAR respectively were also obtained from the agrometerological observatory located near the crop field. The incoming solar radiation (*Rs*) was estimated in the following way and a factor of 0.45 was used (Meek *et al*., 1984) to convert incoming solar radiation values (Rs) into photosynthetically active radiation (PAR).

$$Rs = R_A\ (a + b.\ n/N) \qquad (1)$$

Where R_A = Theoretical amount of radiation that would reach the earth's surface in the absence of the atmosphere.

n = actual duration of sunshine hours.

N = maximum possible duration of sunshine.

a = 0.26 and b = 0.45

The heat units or GDD (thermal time) were computed using mean daily air temperature minus the base (threshold) temperature to correlate and predict the yield of the wheat crop alongwith ET and PAR

(Chakravarty and Sastry, 1989 and Srivastav *et al*., 2000). The base temperature below which wheat crop does not grow is about 5° C (Chowdhury *et al*., 1992) and was used in the study for characterizing thermal response on the yield of the crop.

Based on available phenological data of the observatory, the following growth stages of the crop were considered, namely Sowing to tillering (P_1), Ear emergence to flowering (P_2) and Grain formation to harvest maturity (P_3).

The GDD, PAR and ET were pooled up for each of the above mentioned phenological stages and were used to develop a multiple linear regression equation with grain yield. Each of the three crop growth stages were included in the same equation to correlate the meteorological variables with grain yield taking all 17 years data of the crop in New Delhi.

3.1. Year to year variability in consumptive use of water is observed in Table 1. The total water use by Sonalika variety was in the order of 269.3 mm in 1978-79 to 525.6 mm in 1976-77 and for HD-2009, it ranged from 375.5 (1982-83) to 417.9 mm in (1984-85), where as for HD-2285 variety, it was minimum of 187.9 mm in 1994 and maximum of 406 mm in 1997. The highest water requirement of 418 mm was recorded during 1986-87 at Ambikapur of Madhya Pradesh when five irrigation were applied at critical stages (Mishra *et al*., 1994). Ignoring the crop varieties, the mean ET use by the crop was 363.6 mm with variability of 23%. Analysis of phasewise water use by the wheat crop revealed that mean water use in P_1, P_2 and P_3 stage was 102 mm, 155 mm and 107 mm respectively. Differences in ET of all the phenological stages were evident in different years which was due to variation in duration of crop growing period, microclimatic conditions and cultivars used.

The ratio of crop yield to evapotranspiration known as water use efficiency (WUE), serves as a very useful tool in crop and variety selection for maximum yield per unit of water consumed. The WUE of Sonalika variety was varied from 8.1 kg/ha/mm in 1976-77 to 11.4 kg/ha/mm in 1980-81 and that for HD-2285, it was in the order of 6.2 kg/ha/mm (1997) to 11.2 kg/ha/mm (1994) where as, for HD-2009, it varied from 7.5 (1984-85) to 9.1 kg/ha/mm (1982-83). Ashok Kumar *et al*., (1994) found the maximum WUE of 8.27 kg/ha/mm at ratio of 0.6 irrigation water (0.6 IW) to Cumulative Pan Evaporation (CPE) on HD-2285 variety at Karnal, Haryana.

3.2. Heat unit or GDD is widely used for describing the temperature response to growth and development of crops. Heat unit requirement for completion of different phenophases of wheat were worked out and recorded in Table 1. It was observed that for different sowing dates of three varieties, the mean GDD at P_1 stage was 518 (variability 9%), at P_2 stage 448 (variability 14%) and at P_3 stage, it was 834 with variability 12%. However the accumulated GDD from sowing to maturity of three crops species varied from 1527 during 1976-77 to 1920 during 1978-79 for Sonalika variety, 1753 (1984-85) to 1920 (1982-83) for HD-2009 and for HD–2285 variety, it was 1709 during 1987-88 to 2169 during 1994. Agarwal *et al*. (1999) found that the accumulated GDD ranged from 1690 to 1858 at different dates of sowing and two varieties of wheat crop at Jabalpur, Madhya Pradesh.

TABLE 2

Water use efficiency (WUE), heat use efficiency (HUE) and radiation use efficiency (RUE) of wheat (variety Sonalika, HD-2009 and HD-2285)

Year	Yield (kg/ha)	Total in growth period		
		WUE (kg/ha/mm)	HUE (kg ha^{-1} deg. day^{-1})	RUE (gMJ^{-1})
1976-77	4288	8.1	2.8	1.03
1977-78	4367	8.5	2.6	0.97
1978-79	2680	9.9	1.4	0.55
1979-80	3195	8.3	1.8	0.69
1980-81	3292	11.4	1.9	0.79
1981-82	3458	9.6	2.2	0.83
1982-83	3407	9.1	1.8	0.69
1983-84	3160	8.3	1.7	0.64
1984-85	3126	7.5	1.8	0.68
1985-86	3146	9.3	1.8	0.73
1987-88	3179	8.4	1.9	0.76
1988-89	3150	8.7	1.6	0.65
1989-90	3649	9.3	1.9	0.88
1990-91	2984	11.0	1.6	0.64
1992-93	3097	9.3	1.8	0.76
1994	2110	11.2	1.0	0.41
1997	2550	6.2	1.4	0.60
Mean		9.06	1.8	0.72
SD		1.34	0.42	0.15
CV%		14.74	23.23	20.87

HUE of the crop was also calculated to determined the number of GDD required to produce unit amount of economic grain yield and recorded in Table 2. HUE of the crop varied from 1.4 kg ha^{-1} degree day^{-1} (1978-79) to 2.8 kg ha^{-1} degree day^{-1} (1976-77) in Sonalika variety, 1.7 (1983-84) to 1.8 kg ha^{-1} degree day^{-1} (1982-83 and 1984-85) for HD-2009 and that for HD–2285 variety, it was in the order of 1.0 kg ha^{-1} degree day^{-1} (1994) to 1.9 kg ha^{-1} degree day^{-1} each during 1987-88 and 1989-90.

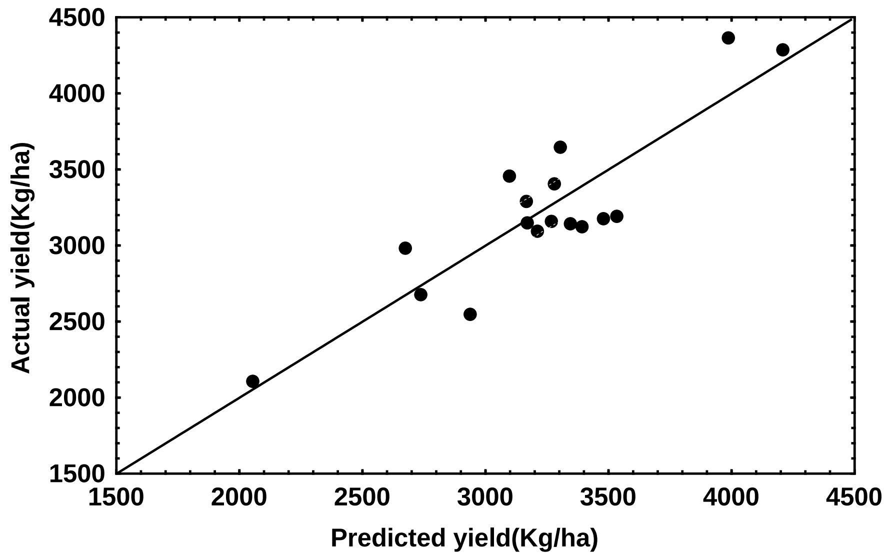

Fig. 1. Comparison between actual and predicted yield of wheat in New Delhi

Rao *et al.* (1999) found the HUE in terms of grain yield in the range of 1.67 kg ha^{-1} degree day^{-1} to 2.56 kg ha^{-1} degree day^{-1} at Hisar, Haryana.

3.3. The phasewise mean PAR value among the three cultivars of wheat crop was 145 MJm^{-2} at P_1 stage, 126 MJm^{-2} at P_2 and 178 MJm^{-2} at P_3 stage. However, the total value from sowing to maturity was varied from 415 MJm^{-2} (1981-82) to 487 MJm^{-2} (1978-79) in Sonalika variety, 458 (1984-85) to 491 MJm^{-2} (1982-83) for HD-2009 and for HD-2285, it was 409 MJm^{-2} (1992-93) to 518 MJm^{-2} (1994). The RUE of wheat in terms of economic grain yield for three crop species varied moderately yearwise and was in the range of 0.55 gMJ^{-1} (1978-79) to 1.03 gMJ^{-1} (1976-77) for Sonalika variety, 0.64 (1983-84) to 0.69 gMJ^{-1} (1982-83) for HD-2009 and 0.41 gMJ^{-1} (1994) to 0.88 gMJ^{-1} (1989-90) for HD-2285. Sharma *et al*. (2000) found the seasonal mean RUE among different wheat cultivars from sowing to harvest maturity period in the range of 1.97 to 2.13 gMJ^{-1} at Hisar, Haryana.

3.4. Differences in grain yield was greatly influenced by different varieties and dates of sowing which could be inferred that agrometeorological variables such as temperature, sunshine hours or radiation and consumptive water use (ET) by the plants played a great role either directly or indirectly in the expression of maturity as well as yield of the crop. The phenophasewise agrometeorological variables (Table 1) were used to develop a multiple linear regression equation with grain yield. The regression equation so developed is

$$Y = 2056.93 + 0.741GDD_1 - 2.661GDD_2 - 0.53GDD_3 + 1.26\ PAR_1 - 0.46\ PAR_2 + 2.31\ PAR_3 - 3.08\ ET_1 + 11.52\ ET_2 + 3.86\ ET_3 \quad (2)$$

Where the subscripts indicate the growth/phenophases results demonstrated that GDD showed negative correlation during flowering and maturity stages and PAR during flowering stage. In case of consumptive water use (ET), exhibited favourable and consistent positive correlation to grain yield during flowering and maturity stages of the crop which may be attributed to application of irrigation in lysimeter tank as well as neighbouring plot/field after crop establishment. So, the crop yield was mainly dependent on consumptive water use (ET) by the crop rather than GDD and PAR. The grain yields were also predicted from the regression equation and presented in Fig. 1 comparing with actual grain yields. The close agreement of actual and predicted yield was supported by high R^2 value (0.79).

4. The following conclusions can be drawn

(*i*) The ET, GDD WUE, HUE, RUE and PAR revealed wide variations in different years and varieties.

(*ii*) The independent variable GDD was negatively correlated whereas consumptive water use (ET) had a positive and consistent correlation with grain yield during flowering and maturity stages.

(*iii*) The model can be used to predict grain yield of the crop which was supported by R^2 value (0.79).

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