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A study on available soil water during the growth of wheat (*Triticum aestivum.L.*) at New Delhi

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सार – इस शोध–पत्र में नई दिल्ली क्षेत्र में गेहूँ (ट्रिटिकम एस्टीवम एल.) के उत्पादन से संबंधित कृषि–मौसम विज्ञानिक पहलुओं का अध्ययन किया गया है। इसके लिए 1985 से 1993 तक की समयावधि में से छः वर्षों के फसल उगने की ऋतु के आँकड़ों का उपयोग किया गया है। गेहूँ की फसल के तैयार होने की संपूर्ण अवधि को छः महत्वपूर्ण अवस्थाओं में विभाजित किया गया है जैसे अंकुरण की अवस्था, किल्लियाँ फूटने की अवस्था,बढ़ने की अवस्था, फूल आने की अवस्था, दाना पड़ने की अवस्था तथा दाना बढ़ने और पकने की अवस्था। फसल की बढ़वार की विभिन्न अवस्थाओं में पानी की आवश्यकता, संपूर्ण फसल के लिए पानी की आपूर्ति, फसल गुणांक और फसल की बढ़वार तथा कुल उत्पादन के संदर्भ में जड़ की गहराई तक मिट्टी में उपलब्ध नमी के अवक्षय पर इसमें चर्चा की गई है।

इस अध्ययन से पता चलता है कि फसल के बढ़ने की अवस्था में जल का सबसे अधिक लगभग 40% तथा शेष मात्रा का उसके बाद फूल आने और दाने के बढ़ने की अवस्था में उपयोग हुआ है। फसल गुणाँक का मान भी फसल की बढ़वार की अन्य अवस्थाओं की तुलना में फसल के बढ़ने की अवस्थाओं में सबसे अधिक (1.1–1.2) रहा और इससे कम मान फूल आने की अवस्था में रहा। फसल तैयार होने की महत्वपूर्ण अवस्था में जड़ की गहराई तक मिट्टी में उपलब्ध नमी के 50 प्रतिशत से अधिक का अवक्षय होने पर पैदावार पर प्रतिकूल असर पड़ने से कुल पैदावार में 18 प्रतिशत तक की गिरावट आई है।

ABSTRACT. Agro-meteorological aspects of wheat (*Triticum aestivum.L.*) at New Delhi have been studied in this paper. A data set of six years during the crop growing season between 1985 to 1993 has been utilized. The growth period of wheat has been divided into six important growth stages *i.e.*, crown root initiation, tillering, elongation, flowering, grain development and maturity. Water requirement of the crop during various stages of its growth, water use efficiency, crop coefficient and available soil water depletion in the root zone in relation to growth and yield of the crop have been discussed.

The study revealed that maximum water is consumed during the elongation stage, nearly 40%, followed by flowering and grain development stage. The crop-coefficient also attains high values (1.1 – 1.2) during elongation stage followed by flowering stage, compared to other growth stages. When available soil water in the root zone depleted by more than 50%, during the critical growth stages of the crop, the yield was adversely affected, upto 18% of the maximum yield.

Key words – Eavapotranspiration, Water use efficiency, Crop coefficient, Water requirement, Crop water stress, Available soil water, Wheat crop.

1. Introduction

Wheat is one of the most important cereal crops in India and occupies prime position among the important food crops in the world. It is extensively grown during the rabi crop season in winter. It is grown over an area of about 27 million hectare with annual production of about 75 million tonnes in the country. The average yield of the crop is 2750 kg/ha. Uttar Pradesh, Punjab and Haryana are the major wheat producing states (SAI 2000). The minimum, optimum and maximum temperatures conducive for the growth of wheat crop are 3-4°C , 25°C and 30-32°C respectively (Venkatraman and Krishnan, 1992). Agro-meteorological conditions cause wide fluctuations in growth, development and yield of the crop. In India, the rainfall amount as well as distribution during rabi season is not favourable for the growth of wheat crop. As such the crop is grown where irrigation facilities are

available. Wheat crop is sensitive to water stress and final yields are affected, particularly when the stress period coincides with the critical growth stages of the crop (IARI, 1977, Bhan *et al*., 1990, Kashyapi and Dubey, 1996, Kashyapi and Das, 1999). So, we need to irrigate the crop in such a way that the crop does not suffer from water stress during the critical growth stages. It may be achieved by irrigating the crop, as soon as available soil water in the root zone depletes to 50% of field capacity. (IARI 1977, ICAR 1997).

In this paper, water requirement during various growth stages, water use efficiency, crop coefficient, available soil water in the root zone in relation to growth and yield of wheat have been studied.

2. Material and methods

The present study is on wheat crop (variety HD 2285) grown at New Delhi (28° 35′ N 77° 12′ E). Six years data during the crop growing season between 1985-86 to 1992-93 have been utilized. The growth duration of the crop was 20 weeks. The soil at the experimental farm was sandy loam with Field Capacity (FC) of 16.6%, Permanent Wilting Point (PWP) of 6.6% and bulk density of 1.6 g/cc. With regard to water need of the crop, the growth period has been divided into six phenological stages (Table 2) *viz*., Crown Root Initiation (CRI), Tillering (T), Elongation (E), Flowering (F), Grain development (GD), and Maturity (M). The total available soil water (Aw), in mm, was calculated using the standard formulae (Michael 1990),

$$Aw = \frac{(FC - PWP)}{100} \times BD \times d \qquad (1)$$

Where,

FC = field capacity in percent.

PWP = permanent wilting point in percent.

BD = bulk density of soil in g/cc.

d = root zone depth in cm.

To calculate the actual available soil water in the soil, FC was replaced by actual soil moisture observation and d = 30 cm has been used in the study.

The water loss of the crop *i.e*., evapotranspiration (ET) was measured with gravimetric lysimeter (1.3 × 1.3 × 0.9 m) fixed within the crop, whereas data on meteorological parameters refer to the observatory located near the experimental farm. The weekly potential evapotranspiration (PET) has been calculated using Penmann's modified formulae (Doorenboss and Pruitt, 1977). The crop coefficient (K_c) was calculated by using the relationship;

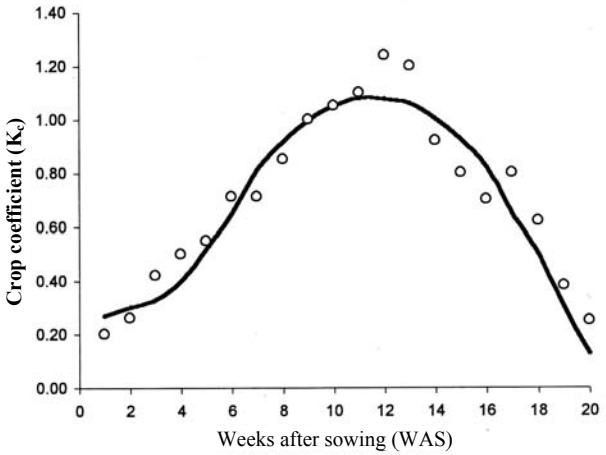

Fig. 1. Variation in average crop coefficient (K_c) with time during the growth of wheat (1985-86 to 1992-93)

$$K_c = \frac{ET}{PET} \qquad (2)$$

3. Results and discussion

3.1. *Crop coefficient (K_c)*

Crop coefficient (K_c) is defined as the ratio of actual evapotranspiration to the potential evapotranspiration and was calculated by using equation (2). A knowledge of K_c seems necessary to determine water requirements of the crop. Fig. 1 shows the variation of K_c with weeks after sowing (WAS). K_c values are found low in the initial stages of growth. K_c values vary in the range 0.2-0.4 during crown root initiation stage and 0.4-0.6 during tillering stage. K_c values then follow a rising trend in the range 0.6-1.2 during the elongation stage. The peak of 1.1-1.2 is attained during this stage between 10-12 WAS. K_c values remain high in the range 1.0-1.2 upto flowering stage. It means the climatic demand for water is high between 10-14 WAS, when the canopy is in good state of health. The crop needs to be irrigated properly during this critical period. If the crop suffers from water stress during this period, it would not be able to evapotranspire at its optimum rate and would certainly hamper growth and adversely affect final yields considerably. There is rapid decrease in K_c values in the range 1.0-0.3 during grain development stage. The K_c values are again low 0.3-0.2 during maturity stage. The values of K_c for wheat during different stages of growth were compared for those given

TABLE 1

Crop yield and distribution of agroclimatic factors during the growth of wheat

Year	Yield (kg/ha)	Actual rainfall (mm)	Deficit/ surplus from normal rainfall (mm)	ET (mm)	W.U.E. (kg/ha/mm)
1985-86	3146	114.2	51.2	322	9.7
1987-88	3179	79.8	16.8	370	8.6
1988-89	3150	93.6	30.6	380	8.3
1989-90	3650	94.7	31.7	386	9.4
1990-91	2983	78.8	15.8	274	10.9
1992-93	3097	32.4	- 30.6	326	9.5
Average	3200	82.2	19.2	343	9.3

by Doorenboss and Kasam (1979) and agreed fairly well. When K_c values were fitted to time, the type of relationship obtained is,

$$K_c = -0.65 + 0.30\ (WAS) - 0.01\ (WAS)^2$$

Using this equation it is possible to estimate K_c values, any time in WAS, during different stages of crop growth.

3.2. *Consumptive use of water (ET) and water use efficiency (WUE)*

Table 1 shows crop yield and distribution of agro-climatic factors during the growth of wheat in different years. Crop yield varied from a low value of 2983 kg/ha during 1990-91 to a high value of 3650 kg/ha during 1989-90. The average yield obtained was 3200 kg/ha. The consumptive use of water (ET) varied from a low value of 275 mm during 1990-91 to a high value of 386 mm during 1989-90. The average amount of water consumed was 343 mm. It may be seen that during 1989-90 when the amount of water consumed was maximum (386 mm), the yield obtained was highest (3650 kg/ha). However, during 1988-89 when the amount of water consumed was nearly same that is 380 mm, the yield obtained was nearly 14 % lower (3150 kg/ha). The ratio of crop yield to evapo-transpiration, 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 and is shown in Table 1. WUE varied from a low value of 8.3 kg/ha-mm during 1988-89 to a high value of 10.9 kg/ha-mm during 1990-91. The average WUE was found to be 9.3. It may be seen that during 1990-91 when WUE was maximum (10.9 kg/ha-mm), the amount of water consumed was lowest (274 mm). Also, during the year 1989-90, when amount of water consumed was maximum (386 mm) the WUE was not maximum (9.4 kg/ha-mm). It clearly indicates that WUE does not depend only on the total amount of water consumed by the crop but also on its distribution during the various growth stages.

Table 2 shows the distribution of amount of water consumed (ET) during various growth stages in different years. The average amount of water consumed in different growth stages was found to be maximum (140 mm) during elongation (E) stage followed by flowering and grain development stage. However, the weekly ET rates during the growth stages crown root initiation, tillering, elongation, flowering, grain development and maturity were found to be 10.0, 15.6, 28.0, 29.5, 13.2, 2 mm respectively. It may be seen that weekly ET rate was highest 29.5 mm and 28.0 mm during the flowering and elongation stages respectively. It means demand for water is highest during these growth stages and crop need to irrigated adequately in such a way that the crop does not suffer from water stress particularly during these growth stages.

3.3. *Available soil water (Aw) in the root zone*

The range of water present in the soil between field capacity and wilting point is known as available soil water (Aw) and was calculated using equation (1). The availability of water to the crop is not uniform in the entire range. As the crop consumes water for its growth, the available soil water in the soil depletes and its availability to the crop also decreases. when the available soil water depletes beyond a threshold limit, the crop begins to experience water stress. The optimum depletion limit of available soil water for wheat has been found to be 50 %. (IARI 1977, ICAR 1997). If the period, in which crop suffers from water stress, coincides with the critical growth stage of the crop and there is delay in applying

TABLE 2

The amount of water consumed (ET) and distribution of rainfall (RF) during the various growth stages in wheat

Growth stage	Weeks after sowing (WAS)	Year												Average
		1985 - 86		1987 - 88		1988 - 89		1989 - 90		1990 - 91		1992 - 93		
		ET (mm)	RF (mm)	ET (mm)	RF (mm)	ET (mm)	RF (mm)	ET (mm)	RF (mm)	ET (mm)	RF (mm)	ET (mm)	RF (mm)	ET (mm)
Crown Root Initiation (CRI)	upto 4	40	21.2	46	6.0	44	1.0	43	0.0	42	42.2	25	0.0	40
Tillering (T)	5 - 7	46	10.4	67	0.0	48	63.6	61	0.0	20	0.0	40	10.4	47
Elongation (E)	8 - 12	133	62.2	156	9.2	140	0.0	140	88.0	120	30.2	150	9.2	140
Flowering (F)	13 -14	62	0.0	42	28.0	56	0.0	77	0.0	44	0.0	72	0.8	59
Grain Development (GD)	15 -18	38	20.4	56	32.8	87	29.0	60	3.4	46	6.4	34	8.0	53
Maturity (M)	19 - 20	3	0.0	3	3.8	5	0.0	5	3.3	3	0.0	5	4.0	4
Total		322	114.2	370	79.8	380	93.6	386	94.7	275	78.8	326	32.4	343

TABLE 3

Frequency of irrigation applied during the various growth stages in wheat

Growth stage	Number of irrigations					
	1985-86	1987-88	1988-89	1989-90	1990-91	1992-93
Crown root initiation (CRI)	–	–	–	–	–	–
Tillering (T)	1	1	–	1	–	–
Elongation (E)	1	1	3	1	1	2
Flowering (F)	1	1	1	1	–	1
Grain Development (GD)	–	–	–	1	1	–
Maturity (M)	–	–	–	–	–	–
Total	3	3	4	4	2	3

irrigation, the crop growth and yields are adversely affected (Hunsigi and Krishna, 1998). So, the scheduling of irrigation needs to be done in such a way that the crop does not suffer from water stress *i.e*., the available soil water does not deplete by more than 50 %, particularly during the critical growth stage of the crop. As rainfall is a parameter that is not evenly distributed during the various growth stages of the crop (Table 2), the exact time and frequency of irrigation varies (Table 3). However, the amount in each irrigation was same *i.e.*, about 65 mm in all the years. The normal seasonal rainfall at the station during the crop growing period is about 63 mm. Fig. 2 to Fig. 7 shows variation of available soil water (Aw) with time during the growth of wheat. The dotted line in the figures, when available soil water (Aw) = 24 mm, indicates the allowable depletion limit of 50 %.

In the year 1985-86, the crop received three irrigations, 114.2 mm of rainfall and consumed a total of 322 mm of water. It may be seen (Table 2) that crop consumed water less than average during elongation and grain development stage. In Fig. 2 it may also be seen that crop suffered from water stress mainly during the elongation stage, when Aw reduced to 13 mm (*i.e.*, 73 % depletion). In this season, the crop could not achieve optimum yield and it was 14 % lower than the maximum yield (3650 kg/ha) obtained in 1989-90. In the year 1987-88, the crop received three irrigations, 79.8 mm rainfall and consumed a total of 370 mm of water. It may be seen (Table 2) that crop consumed nearly 30 % less water than average, during flowering stage. In Fig. 3 it may also be seen that crop suffered from water stress mainly during tillering and elongation growth stages. In the tillering

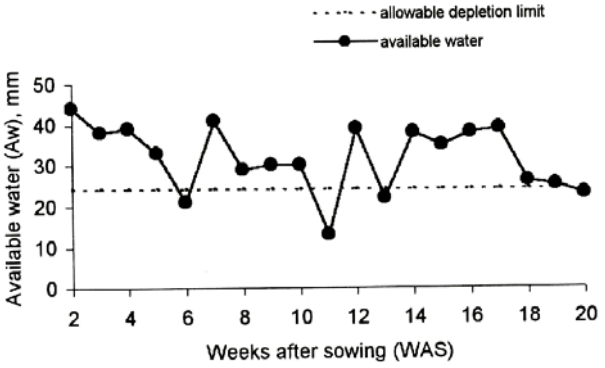

Fig. 2. Variation of available soil water (Aw) with time (1985-86)

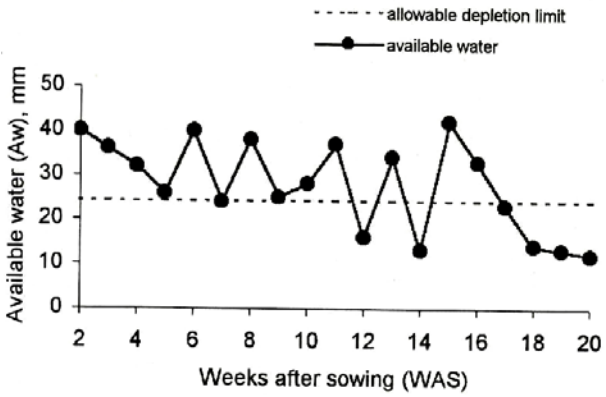

Fig. 5. Variation of available soil water (Aw) with time (1989-90)

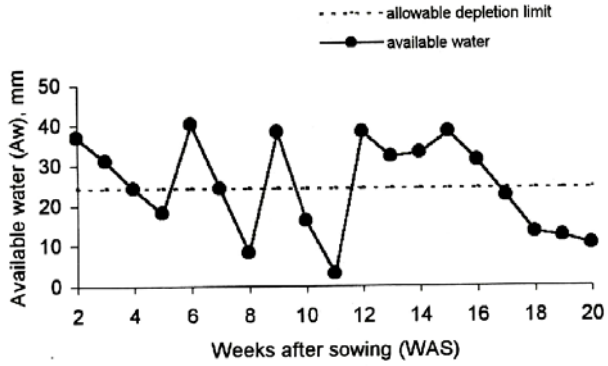

Fig. 3. Variation of available soil water (Aw) with time (1987-88)

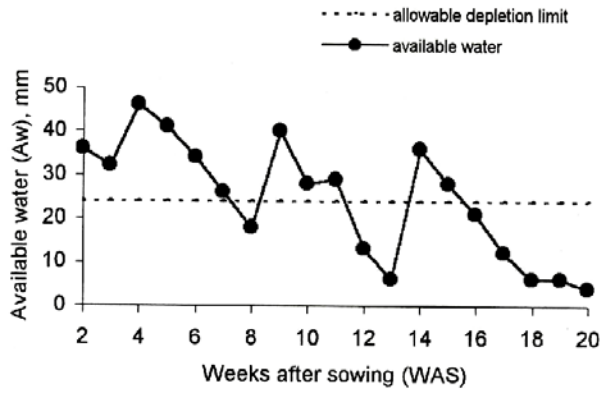

Fig. 6. Variation of available soil water (Aw) with time (1990-91)

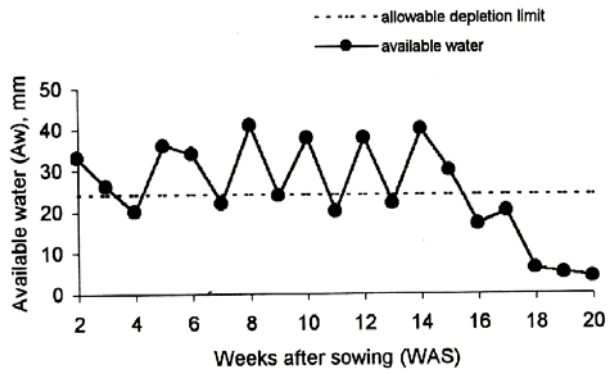

Fig. 4. Variation of available soil water (Aw) with time (1988-89)

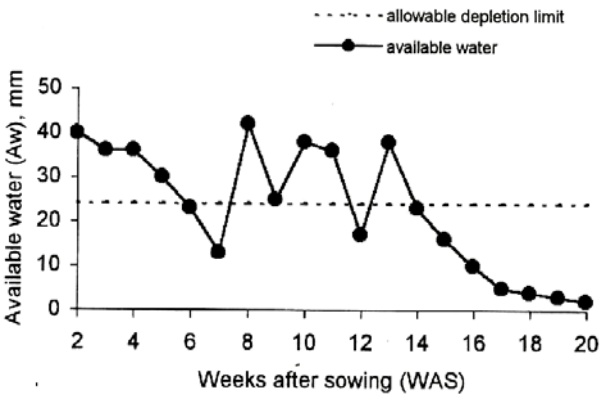

Fig. 7. Variation of available soil water (Aw) with time (1992-93)

stage, Aw reduced to 18 mm (*i.e.*, 63 % depletion). In the elongation stage, Aw reduced upto 3 mm (*i.e.*, 94 % depletion). In this season, the crop could not achieve optimum yield and it was 13 % lower than the maximum yield. In the year 1988-89, the crop received four irrigations, 93.6 mm rainfall and consumed a total of 380 mm of water. It may be seen (Table 2) that crop consumed more than average water in all the growth stages. However, in Fig. 4, it may be seen that crop suffered from water stress during crown root initiation and grain development stage. In the crown root initiation stage Aw reduced to 20 mm (*i.e.*, 58 % depletion). Also, in the grain development stage Aw reduced to 17 mm (*i.e.*, 64 % depletion). In this season, the crop could not achieve optimum yield and it was 13 % lower than the maximum yield.

In the year 1989-90, the crop received four irrigations, 94.7 mm rainfall and consumed a total of 386 mm of water. The crop consumed more than average water in all the growth stages. In Fig. 5 it may be seen that crop did not suffer from water stress for prolonged periods. In this season, the crop could produce maximum yield of 3650 kg/ha. In the year 1990-91, the crop received two irrigations, 78.8 mm rainfall and consumed a total of 275 mm of water. In this year the crop water requirement was not satisfactorily met during the various growth stages. In Fig. 6 it may be seen that crop suffered from water stress mainly during the critical flowering stage and grain development stage. In the flowering stage, Aw reduced to 6 mm (*i.e*., 87 % depletion). Where as, in the grain development stage Aw reduced to 12 mm (*i.e*., 75 % depletion). In this season, the crop could not achieve optimum yield, and it was 18 % lower than the maximum yield. In the year 1992-93, the crop received three irrigations, 32.4 mm rainfall, and consumed a total of 326 mm of water. The crop consumed less than average water during crown root initiation, tillering and grain development stage. In Fig. 7, it may been seen that crop suffered from water stress mainly during tillering and grain development stage. In the tillering stage, Aw reduced to 13 mm (*i.e*., 73 % depletion). Where as, in the critical grain development stage, Aw reduced to 5 mm (*i.e*. 90 % depletion). In this season, the crop could not achieve optimum yield and it was 15 % lower than the maximum yield.

In the light of above discussion it may be concluded that in order to achieve high WUE and optimum crop yield, wheat crop requires atleast four well distributed irrigations, along with normal rainfall of 63 mm. The irrigation should be applied as soon as available soil water depletes to more than 50 %.

4. Conclusions

(*i*) The total water consumed by wheat crop varied between the range 275 mm to 386 mm, with an average of 343 mm. The crop yield does not depend only on the total amount of water consumed by the crop but also on its distribution during the various growth stages.

(*ii*) Maximum water is consumed during the elongation stage, nearly140 mm, followed by flowering and grain development stage. The crop-coefficient also attains high values (1.1–1.2) during elongation stage followed by flowering stage, compared to other growth stages.

(*iii*) When available soil water (Aw) in the root zone depleted by more than 50 %, during the critical growth stages of the crop, the crop suffered from water stress and yield was adversely affected. The crop suffered highest yield loss, upto 18 % of the maximum yield, when Aw reduced upto 6 mm (*i.e*. 87 % depletion) during flowering stage and Aw reduced upto 12 mm (*i.e*. 75 % depletion) during grain development stage.

(*iv*) In order to achieve high WUE and optimum crop yield, wheat crop needs atleast four well distributed irrigations, along with normal rainfall of 63 mm. The irrigation should be applied as soon as available soil water depletes to more than 50 %.

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