556.18 : 631.671 : 633.11

A STUDY ON WATER REQUIREMENT AND AVAILABLE WATER IN THE ROOT ZONE IN VARIOUS GROWTH STAGES OF WHEAT AT DHARWAR

1. Wheat occupies prime position among the important food crops of the world. Wheat is considered as one of the most important cereal crops in India. Latitudinal distribution of growing of this crop is wide and best adaptation of the crop is in areas with moderate temperature and sub humid to semiarid conditions. It is extensively grown during Rabi crop season in winter. It is grown over an area of about 27 million hectare with annual production of about 75 million tones in the country. The average yield of the crop is 2750kg/ha (SAI 2000). Uttar Pradesh, Punjab and Haryana are the major wheat producing states. Cool climate during early growth and hot climate nearing maturity are conducive for good growth and yield of wheat crop; however various agrometeorological conditions may cause wide fluctuations in growth, development and yield of the crop. It is a well-known fact that rainfall during Rabi season is not favourable for wheat crop; hence the crop is grown in areas where assured irrigation facilities are available. Wheat crop is sensitive to water stress and final yields are adversely affected, particularly when the stress period coincides with the critical growth stage of the crop. (IARI 1977, Bhan *et al*., 1990, Kashyapi and Dubey 1996). In order to achieve good growth and yield, the crop needs to be irrigated adequately in such a way that the crop does not suffer from water stress during the critical growth stages. In case of wheat, it may be achieved by irrigating the crop, whenever available water in the root zone depletes to 50% (IARI 1977).

In this paper, water requirement, water use efficiency, crop coefficient, available water in the root zone in relation to growth and yield of wheat have been studied for six important growth stages *viz*., crown root initiation, tillering, elongation, flowering, grain development and maturity.

2. The present study is based on wheat crop (*variety* DWR-39) grown at Dharwar (15° 26' N, 75° 07' E, 678 masl) in Karnataka. The climate of Dharwar is semi-arid. The normal annual rainfall at the station is about 815 mm, whereas seasonal rainfall (Rabi) is about 65 mm. A data set of five years (meteorological, agrometeorological and soil moisture data) during the Rabi season between 1989-90 to 1993-94 has been utilized to study water requirement, water use efficiency, crop coefficient and available water in the root zone in relation to growth and yield of wheat. The soil at experimental farm was clay loam with field capacity (FC) of 35%, permanent wilting point (WP) of 15% and bulk density of 1.23 g/cc. The crop was sown during second fortnight in October and harvested during first fortnight in February. The growth duration of the crop was about 16 weeks. With regard to water need of the crop, the growth period of wheat, in this study, has been divided into six important growth stages *viz*., crown root initiation (CRI) *i.e*., growth stage up to 3 weeks after sowing (WAS); tillering (T) 4-5 WAS; elongation (E) 6-9 WAS; flowering (F) 10-11 WAS, grain development (GD) 12-14 WAS; and maturity (M) 15-16 WAS.

The actual evapotranspiration (AET) was measured from the gravimetric Lysimeter (1.3 × 1.3 × 0.9 m) fixed within the crop field, whereas data on meteorological parameters (maximum and minimum temperatures, relative humidity, sunshine hours and wind speed) which refer to the observatory located near the experimental farm was obtained from the records of India meteorological department, Pune. 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 following relationship,

$$K_c = AET / PET \quad (1)$$

The total available water (Aw) in the root zone (up to 90 cm. depth) was calculated using the following standard formulae (Michael 1990);

where,

$$Aw = \sum_{i=0}^{i=90} [(FC - WP)/100] \times BD \times d_i \quad (2)$$

FC = field capacity, percent.

WP = permanent wilting point, percent.

BD = bulk density of soil, g/cc.

d_i = root zone depth, cm.

To calculate the actual available water in the root zone, FC was replaced by actual soil moisture observations.

3.1. Crop coefficient (K_c) is defined as the ratio of actual evapotranspiration to the potential evapotranspiration. Knowledge of K_c seems necessary to determine the water requirement of the crop. K_c values

TABLE 1

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

Year	Yield (kg/ha)	Rainfall (mm)	ET (mm)	W.U.E. (kg/ha/mm)
1989-90	2196	76.9	417.0	5.26
1990-91	2367	56.8	341.0	6.94
1991-92	1535	3.4	350.0	4.38
1992-93	1642	138.3	367.0	4.47
1993-94	1861	56.0	433.0	4.29

TABLE 2

The amount of water consumed (ET) during the various growth stages in wheat

Growth stages	Year					Average
	1989-90 ET (mm)	1990-91 ET (mm)	1991-92 ET (mm)	1992-93 ET (mm)	1993-94 ET (mm)	
Crown root initiation (CRI)	73.8	44.7	72.0	78.6	63.0	66.4
Tillering (T)	44.8	66.6	67.4	87.8	83.4	70.0
Elongation (E)	114.0	132.8	95.2	130.4	142.4	123.0
Flowering (F)	66.0	42.2	37.8	30.2	64.4	48.1
Grain development (GD)	99.3	47.7	66.0	33.6	67.5	62.8
Maturity (M)	19.1	7.0	11.6	6.4	12.3	11.3
Total	417.0	341.0	350.0	367.0	433.0	381.6

during different growth stages were calculated by using Eqn. 1. K_c values were found to vary in the range 0.40-0.75 during crown root initiation, 0.80-1.00 during tillering, 1.00-1.15 during elongation stage, 1.00-0.90 during flowering, 0.90-0.60 during grain development and 0.30-0.20 during maturity. It means that crop coefficient attain the highest values in the range 1.00-1.15 during the elongation stage of the crop. It further means, the climatic demand for water is high during this period and crop needs to be irrigated adequately during this 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. The values of K_c for wheat during different growth stages were compared with those given by Doorenboss and Kasam (1979) and agreed fairly well. When K_c values were fitted to time, in WAS, the following non-linear relationship (r = 0.95) is obtained,

$$K_c = 0.153 + 0.262 \times (\text{WAS}) - 0.0165 \times (\text{WAS})^2$$

3.2. Table 1 shows crop yield and distribution of water production factors during the growth of wheat in different years. Crop yield varied from a low value of 1535 kg/ha during 1991-92 to a high value of 2367 kg/ha during 1990-91. The consumptive use of water (ET) varied from a low value of 341 mm during 1990-91 to a high value of 433 mm during 1993-94. The average amount of water consumed was about 382 mm. Water use efficiency (WUE), which is defined as the ratio of crop yield to the total amount of water consumed (ET), serves as a very useful tool in crop and variety selection for obtaining maximum yield per unit of water consumed. WUE varied from a low value of 4.38 kg/ha/mm during 1991-92 to a high value of 6.94 kg/ha/mm during 1990-91. The average WUE was found to be 5.0 kg/ha/mm. It may be seen that during 1990-91 when WUE was maximum, the amount of water consumed was not the maximum. Similarly, during 1993-94 when maximum amount of water was consumed, the crop yield was not the maximum. 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 (123.0 mm),

TABLE 3

Distribution of rainfall during the various growth stages in wheat

Growth stage	Year				
	1989-90 Rainfall (mm)	1990-91 Rainfall (mm)	1991-92 Rainfall (mm)	1992-93 Rainfall (mm)	1993-94 Rainfall (mm)
Crown root initiation (CRI)	0.0	34.8	3.4	138.3	8.4
Tillering (T)	0.0	22.0	0.0	0.0	0.0
Elongation (E)	44.4	0.0	0.0	0.0	38.4
Flowering (F)	7.4	0.0	0.0	0.0	0.0
Grain development (GD)	25.1	0.0	0.0	0.0	8.0
Maturity (M)	0.0	0.0	0.0	0.0	0.0
Total	76.9	56.8	3.4	138.3	56.0

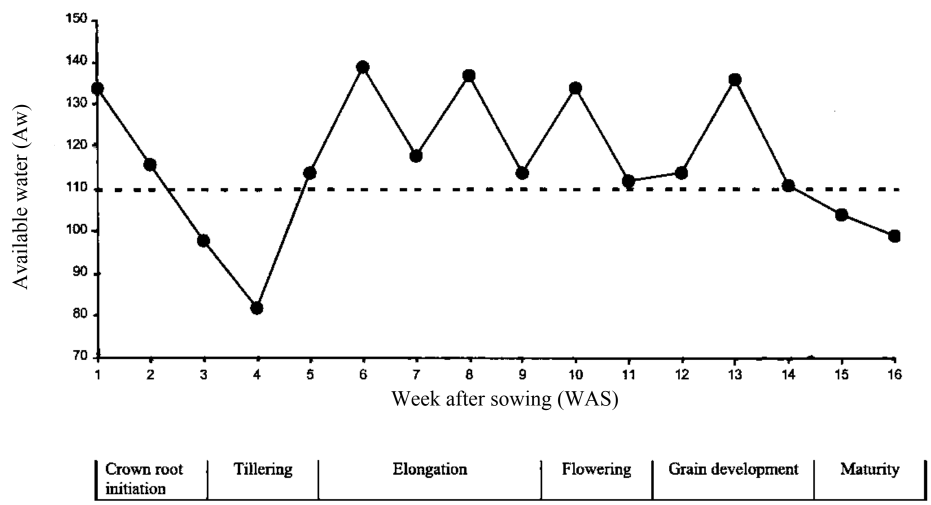

Fig. 1. Changes in available water (Aw) in different phonological stages during the growth of wheat in 1989-90

nearly 32%, during elongation (E) followed by tillering and crown root initiation stage. However, the weekly ET rates were found to be 22.1, 35.0, 30.7, 24.0, 20.9 and 5.6 mm for the growth stages crown root initiation, tillering, elongation, flowering, grain development and maturity respectively. It may be observed that weekly ET rate was highest (35.0 mm) during tillering stage followed by elongation stage (30.7 mm). It means demand for water is highest during these growth stages and crop need to be irrigated adequately in such a way that crop does not suffer from water stress particularly during these growth stages.

3.3. The range of water present in the soil between field capacity and wilting point is known as available water and was calculated using Eqn. 2. The availability of the water to the crop is not uniform throughout the entire range. As the crop consumes water for its growth, the available water in the soil depletes and its availability to the crop also decreases. When the available water depletes beyond a threshold limit, the crop begins to experience water stress. The optimum depletion limit of available water for wheat has been found to be 50% in the root zone (IARI 1977, ICAR 1977). When available water depletes by more than 50% in the root zone, the crop suffers from water stress and more water is lost as evaporation than consumed by the crop for its transpiration. When this stress period coincide with the critical growth stage of the crop and there is delay in applying irrigation, the crop growth and yields are adversely affected (Hunsigi and Krishna, 1998). The important growth stages that are considered critical, with regard to irrigation, are crown root initiation, flowering and grain development. The crop needs to be irrigated

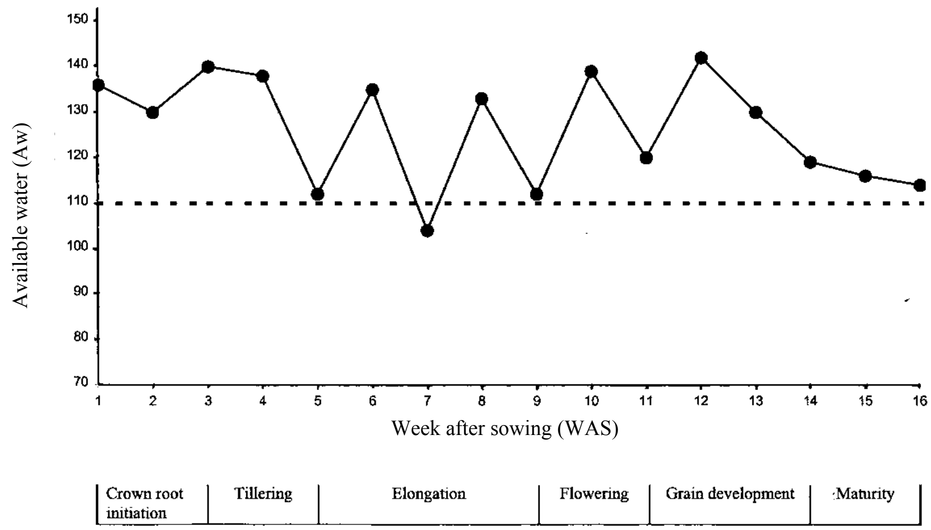

Fig. 2. Changes in available water (Aw) in different phonological stages during the growth of wheat in 1990-91

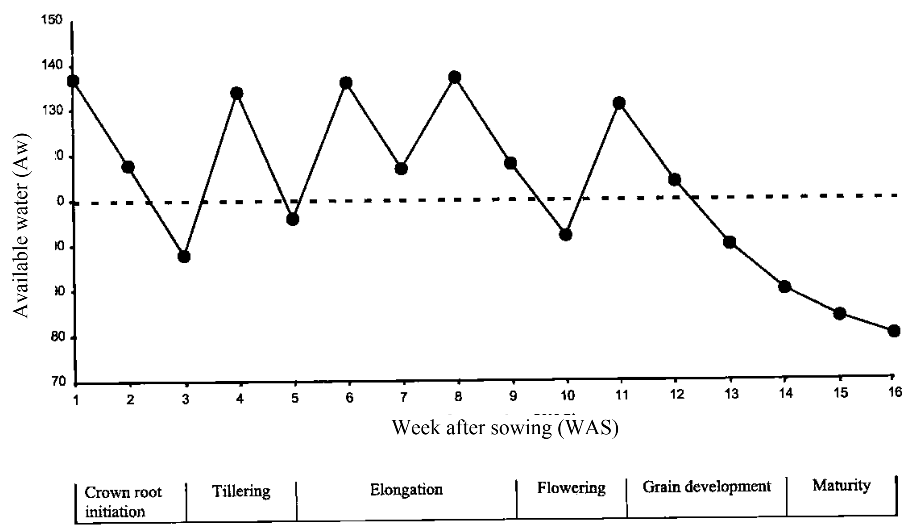

Fig. 3. Changes in available water (Aw) in different phonological stages during the growth of wheat in 1991-92

adequately, particularly during these critical growth stages, so that crop does not suffer from water stress *i.e.* the available water in the root zone does not deplete by more than 50%. Available water depletion in the root zone (90 cm depth) for different years in relation to crop yield is discussed below.

As rainfall is a parameter that is not evenly distributed during the various growth stages of the crop (Table 3), the timing of irrigation also changes accordingly. The normal seasonal rainfall at the station during the crop growing period is about 65 mm (IMD 1999). As this amount of water is not sufficient for raising the crop, it is grown with 4-5 supplementary irrigations of about 70-80 mm each. Figs. 1 to 5 shows changes in available water (Aw) in different phonological stages during the growth of wheat in different years. The dotted line in the figures, when available water (Aw) = 110 mm, indicates the allowable depletion limit of 50%. In the year 1989-90, the crop received 76.9 mm rainfall, which was 18% more than normal rainfall. The crop consumed a total of 417 mm water, which was about 9% higher than the average. It may be seen (Table 2) that crop consumed about 35% less water, than average, during the tillering

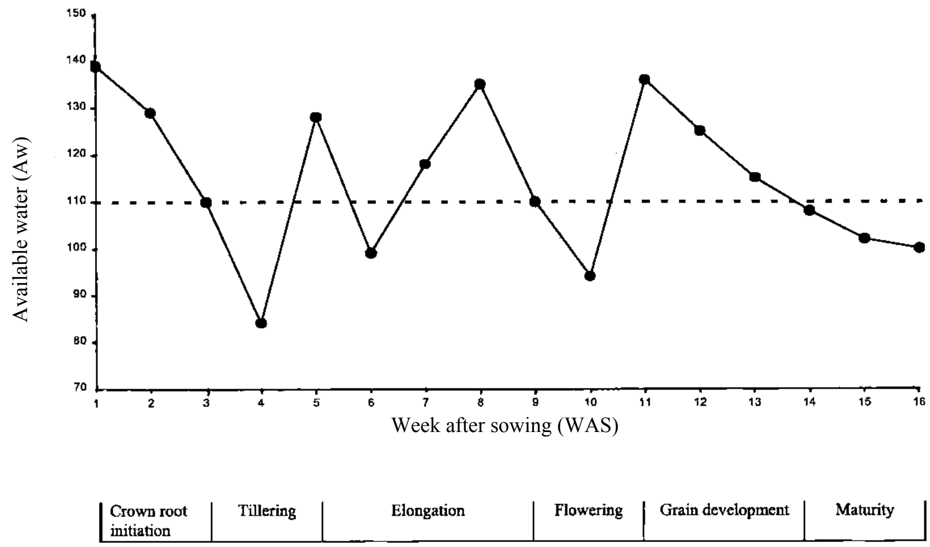

Fig. 4. Changes in available water (Aw) in different phonological stages during the growth of wheat in 1992-93

stage. In Fig. 1. it may be observed that crop suffered from water stress i.e. available water depleted below 50%, mainly during crown root initiation and tillering stage, in the 3rd and 4th WAS, for a period of about 12 days, when available water in the root zone reduced to 82 mm *i.e.*, depletion reached 38%. As such the crop could not achieve optimum yield. In this year, yield obtained was 2196 kg/ha, which was 7% lower than the maximum yield of 2367 kg/ha during 1990-91.

In the year 1990-91, the crop received 56.8 mm rainfall, which was 12% lower than normal rainfall. The crop consumed a total of 341 mm of water, which was about 10% less than average. It may be seen (Table 2) that crop consumed less water, than average, during the crown root initiation and grain development stage. In Fig. 2. it may be observed that crop did not suffer from water stress for a significant period *i.e.*, available water in the root zone did not deplete below 50%, any time during the growth of the crop. As such the crop could produce maximum yield of 2367 kg/ha.

In the year 1991-92, the crop received only 3.4 mm rainfall, which was about 95% lower than normal rainfall. The crop consumed a total of 350 mm of water, which was about 8% lower than the average. It may be seen (Table 2) that crop consumed significantly less water, about 20% less than average, during the elongation and flowering stage. In Fig. 3. it may be observed that crop suffered from water stress at regular interval and particularly during the critical (crown root initiation and flowering) growth stages. During the critical crown root initiation stage, in the 3rd WAS, for a period of about 5 days, available water in the root zone reduced to 98 mm *i.e.*, depletion reached 45%. During the critical flowering stage, in the 10th WAS, for a period of about 4 days, available water in the root zone reduced to 102 mm, *i.e.*, depletion reached 47%. As such the crop could not achieve optimum yield. In this year, the yield obtained was 1535 kg/ha, which was 35% lower than the maximum yield.

In the year 1992-93, the crop received 138.3 mm of rainfall, which was nearly double in amount of the normal rainfall. However, the rainfall was not evenly distributed (Table 3), but concentrated mainly during the crown root initiation stage of the crop. The crop consumed a total of 367 mm of water, which was about 5% less than average. In this year, the crop consumed significantly lower amount of water during the flowering and grain development stage (Table 2). In Fig. 4. it may be seen that crop suffered from water stress *i.e.* available water in the root zone depleted by more than 50%, at regular interval and also particularly during the flowering stage, in the 10th WAS, for a period of about 7 days, when available water in the root zone reduced to 94 mm *i.e.*, depletion reached 43%. As such, the crop could not achieve optimum yield. In this year, the yield obtained was 1642 kg/ha, which was, nearly 30%, lower than the maximum yield.

In the year 1993-94, the crop received 56.0 mm rainfall, which was about 14% less than normal rainfall. The crop consumed a total of 433 mm of water, which was about 13% higher than average. In this year, the crop

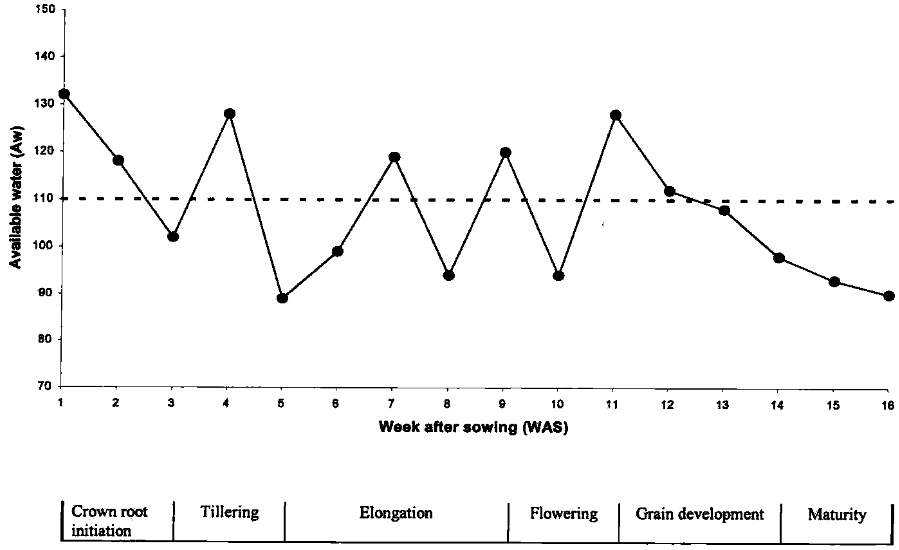

Fig. 5. Changes in available water (Aw) in different phonological stages during the growth of wheat in 1993-94

did not consume less than average water in any of the growth stages. However, it may be observed in Fig. 5. that available water depleted below the 50% depletion limit, at regular interval and particularly during the critical (crown root initiation and flowering) growth stages. During the critical crown root initiation stage, in the 3rd WAS, for a period of about 4 days, the available water in the root zone reduced to 102 mm *i.e.*, depletion reached 47%. During the critical flowering stage, in the 10th WAS, for a period of about 4 days, when available water in the root zone reduced to 94 mm. *i.e.*, depletion reached 43%. It may be noted that in this year, although ET loss was more than average, but when the available water in the root zone depletes below 50%, the crop experiences water stress and as a result more water is lost as evaporation than actually consumed by the crop. As a result crop growth and yield is adversely affected. In this year, the yield obtained was 1861 kg/ha, which was 22% less than the maximum yield.

In the light of the above discussion it may be concluded that in order to achieve high WUE and optimum crop yield, the crop needs to be irrigated adequately by maintaining the available water in root zone to more than 50%, particularly during the critical growth stages such as crown root initiation and flowering and also during the elongation stage, when water demand of the crop is high.

4. (*i*) The water consumed by the crop varied between the range 341 mm to 433 mm, with an average of 382 mm and maximum water, nearly 32%, is consumed during the elongation stage.

(*ii*) The crop yield and 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.

(*iii*) The crop coefficient attains the highest values, in the range 1.00-1.15, during the elongation stage of the crop.

(*iv*) Maximum yield is obtained when the crop does not suffer from water stress at any time during the growth period of the crop.

(*v*) When available water in the root zone depleted by more than 50%, particularly during the critical growth stages of the crop, the yield was adversely affected, up to 35%, of the maximum yield.

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