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Profile wise soil moisture extraction pattern of wheat and maize

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Abstract
A field experiment was conducted to find out profile wise soil moisture extraction pattern from effective root zone depth of wheat and maize for which soil moisture uptake from each soil layer was determined as difference of moisture content between two successive moisture measurement dates or within one irrigation cycle. The results of this study indicated that maximum 56.1 percent moisture has been extracted from the top (0-30 cm) soil layer for both the crops and the moisture uptake decreased abruptly from the lower soil profiles. Moisture extraction from 30-60 cm soil depth amounted to 25.4 and 24.8 percent, respectively for wheat and maize whereas depletion was 18.5 percent from 60-90 cm soil depth for both the crops. Moisture extraction pattern was almost similar for both the crops and they showed a declining pattern of moisture uptake from upper to lower soil profiles of crop root zone. Total water uptake for the respective crops were calculated to be 143.5 and 235.5 mm with crop water use efficiency as 22.64 and 14.89 kg.ha.mm^{-1}.On the basis of moisture extraction patterns, estimation of crop water requirement and thereby better irrigation scheduling of wheat and maize crops can be planned for the agro-climates having similar soil-moisture characteristics in different layers of the root zone.

Keywords: Crop root zone, evapotranspiration, irrigation, moisture extraction, soil–water

Introduction
Efficient use of available water resources requires a clear understanding of water use as well as soil moisture extraction pattern of the crops. Moisture extraction from plant roots is a key process for plant growth and transport of water in the soil–plant system. Moisture extraction pattern shows the relative amounts of moisture uptake from different soil depths within the crop root zone. It is generally employed to determine the water use of irrigated crops grown in fairly uniform soils when depth to ground water is such that it will not influence the soil moisture fluctuation within the root zone. It provides key information for optimum irrigation scheduling also.The rate of water use by the crops depend on profile water storage, type of crop, stage of crop growth, soil type, weather, rooting characteristics etc. The root system extracts different volumes of moisture from the root zone, which is a function of location (depth from ground), moisture content and time.

Stratified use of soil moisture and nutrients may also improve the overall water use efficiency in cropping systems (Roader *et al.*, 1989) [1].The movement of water from soil to plant roots has been studied for a wide variety of plant species across a range of dry and wet climate. Kumar *et al.* (1986) [2] conducted experiment on moisture extraction pattern by wheat genotypes in irrigated and unirrigated conditions, Cabelguenne and Debaeke (1998) [3] developed model of the soil water extraction capacities of maize, sunflower, soya bean, sorghum and wheat, Kondol *et al.* (2000) [4] studied characteristics of root growth and water uptake from soil in upland Rice and Maize. Huang (2004) [5] modelling soil water regime with corn yields considering climatic uncertainty whereas Mthandi *et al.* (2013) [6] conducted experiment on root zone moisture distribution in maize and Rudnick and Irmark (2014) [7] developed soil-water extraction model of maize.

Wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are major crops grown during Rabi season in North Bihar. The information regarding contribution of different soil layer on moisture use by these crops is scanty. Thus, present study was conducted to find out pattern of moisture extraction from different soil layers of crop root zone of wheat and maize to predict the water uptake by plants in agro-climate of Pusa, Bihar (India) which falls under Gandak command area.

Materials and Methods

Experimental site

Field experiment was carried out at Water Management Research Farm of Dr. Rajendra Prasad Central Agricultural University, Pusa previously known as Rajendra Agricultural University, Pusa, Bihar to find out soil moisture extraction pattern of Wheat (Triticum aestivum L.) and Maize (Zea mays L.) crops. The experimental site is situated at 25.98° N Latitude and 85.67° E longitude at an elevation of 52 meter above the mean sea level. The climate of the area is humid subtropical with average annual rainfall of 1270 mm out of which nearly 80.75 percent occurs in monsoon months. The soil of the study area has uniform topography, well drained, good tilth with easily workable soil.

Field layout & Experimental Detail

The field trials of wheat and maize crops were conducted in a randomised block design with plot size of 5 m X 3 m in five replications and 1 m buffer has been maintained between two adjacent plots. Wheat (Triticum aestivum L.) var. UP 262 and maize (Zea mays L.) var. Laxmi were raised during the Rabi season with recommended agronomical practices. Crops were sown in lines by opening furrows with the help of hand hoe in which seed rate of 125 $kg.ha^{-1}$ and 20 $kg.ha^{-1}$ have been used for the respective crops. The treated seeds were sown with row spacing of 20 cm and 60 cm and plant spacing of 5 cm and 20 cm, respectively at 4-5 cm soil depth for wheat and maize crops. Furrows were again fully covered with soil after sowing. Recommended dose of fertilisers (120:60:40 and 120:75:50, N: P: K for wheat and maize, respectively) were applied plot wise. Full dose of phosphorus and potash were applied manually in lines 8-10 cm apart from main line of seed at a depth of 4-5 cm but nitrogen was applied in three split doses: 50 percent as basal dose, 25 percent after first irrigation and 25 percent after second irrigation. The measured quantity of irrigation water was applied in check basin (each plot) time to time using a 7.5 cm parshall flume in order to maintain the soil moisture level in the effective root zone to the field capacity on the basis of soil moisture content monitored prior to each irrigation.

Weather Data Collection

Daily values of weather parameter like pan evaporation and rainfall data for the experimental period were obtained from observatory located in Rajendra Agricultural University, Pusa (Bihar).

Profile wise Soil Moisture Determination

In order to know the soil moisture extraction pattern, profile wise soil moisture content along with quantity of moisture use were determined. Yield attribute of both the crops were also recorded for estimation of water use efficiencies of wheat and maize.

Soil moisture extraction from the effective root zone depth for different periods between two successive soil sampling was worked out by measuring soil moisture content. In order to assess the moisture status at any time in between two irrigations, moisture was measured gravimetrically for which soil samples were collected on different dates prior to each irrigation from sowing to harvest with the help of tube auger from 0-30, 30-60 and 60-90 cm depths from each plot of wheat and upto 120 cm depths for maize crop and average soil moisture was used as a basis to irrigate the crop. Intermittent soil samples were also collected. Rainfall occurred during the growing season was taken into account in calculations. Due to low intensity of rainfall, the total amount recorded was considered as effective.

Determination of Soil Moisture Extraction Pattern

Soil moisture extraction studies involved measurement of soil moisture from various depths at a number of times throughout the growing period. In calculating layer wise water depletion during growing period of crops, the moisture data for each 30 cm of root zone was used. Moisture extraction for all the time periods between two successive soil moisture measurement dates were determined from each soil layer of effective root zone by using the equation given below:

$$u = \sum_{i=1}^{n} \frac{(SW_{1i} - SW_{2i})*BD_i*D_i}{100} \qquad (1)$$

where, u = Soil moisture depletion from crop root zone for successive sampling periods or within one irrigation cycle (cm), SW_{1i}=Initial soil moisture moisture content in the i^{th} layer (percent), SW_{2i}=Final soil moisture moisture content in the i^{th} layer (percent), BD_i=Bulk density of the i^{th} layer of soil (gcm^{-3}), D_i= Depth of the i^{th} layer of the soil (m), n= Number of soil layers sampled in the root zone depth D

Soil moisture depletion for the period of different irrigation cycle was computed as difference of field capacity moisture content and the final moisture content at the end of that irrigation cycle.

Bulk density was determined by core cylinder method for which samples were collected from all the soil profiles upto 90 cm and 120 cm, respectively for wheat and maize crops with 30 cm depth intervals. The effective root zone depth was calculated by using the model of Borg and Grimes (1986)[8], in which rooting depth followed a sigmoid pattern with time irrespective of plant species, soil type and water regime. This model was selected because it estimated rooting depth as a function of time and is given as:

$$RD = RD_m \left[0.5 + 0.5\sin\left(3.03\,t_r - 1.47\right)\right] \qquad (2)$$

Where, RD= Rooting depth on day t (cm), RD_m = Maximum expected rooting depth (cm), 90 cm for wheat, 120 cm for maize, t_r = Relative time (t/t_m) and t_m= Time to attain physiological maturity (Days after sowing), 110 for wheat, 130 for maize.

Weekly record of fluctuations in the ground water table in a well located near the experimental site were taken to find out the contribution of ground water in the effective root zone of the crop.

Total water use of crop was determined by summing up the soil moisture depletion from all the depths and all the periods as given below:

$$C_u = \sum_{i=1}^{n} u \qquad (3)$$

Where, C_u = Total water use of crop (cm), u = soil moisture depletion from crop root zone for successive soil sampling periods or within one irrigation cycle (cm)

The crop water use efficiency was computed using the under mentioned relationship to determine how effectively the irrigation water was used by the crop:

$$WUE = \frac{Y}{C_u} \quad (4)$$

Where, WUE= Crop water use efficiency (Kg.ha.mm^{-1}), Y= Crop yield (Kg), C_u = Total water use of crop (mm).

Results and Discussion

The results of the field experiments have been presented in this section. Particle size of different layers of soil was worked out by Master sizer whereas bulk density and field capacity has been determined using core sampler and data has been presented in Table 1.

Table 1: Soil textural properties, bulk density and field capacity of different soil layers

Soil depth (cm)	Particle size distribution (%)			Soil Textural Class	Bulk density (Mg.m^{-3})	Field capacity (cm3.cm^{-3})
	Clay	Sand	Silt			
0-30	7.50	49.18	43.32	Sandy loam	1.45	0.349
30-60	10.01	46.66	43.33	Loam	1.47	0.386
60-90	11.43	34.73	53.84	Silt loam	1.53	0.422
90-120	10.55	44.23	45.22	loam	1.58	0.390

Fig. 1 showed trends of weekly evaporation and rainfall data whereas Fig.2 highlighted the variation of weekly water table depth at the experimental site throughout the

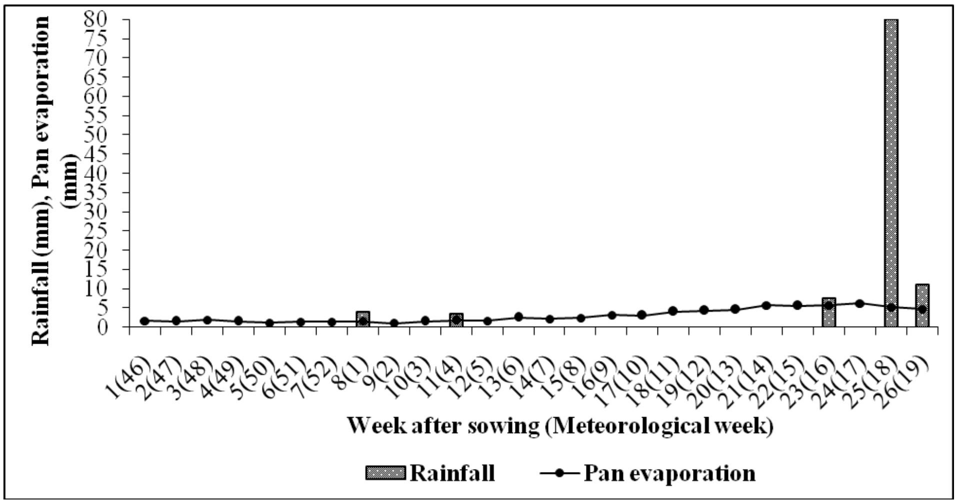

Fig 1: Trends of weekly evaporation and rainfall data of the study area

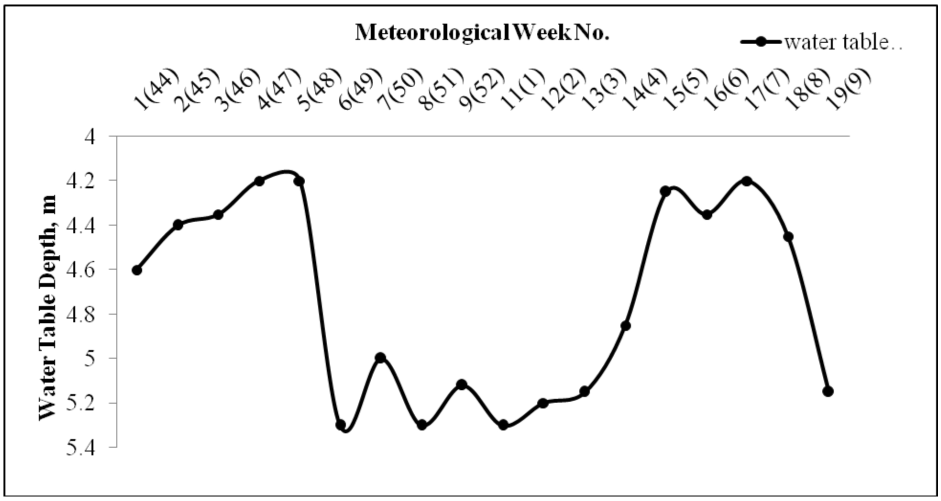

Fig 2: Variation of weekly water table depth at the experimental site

Crop period which indicated that ground water level during crop period were much below i.e. (below 4.0 meter), thus ground water contribution has been neglected. Simulated rooting depth of both the crops has been given Fig.3.

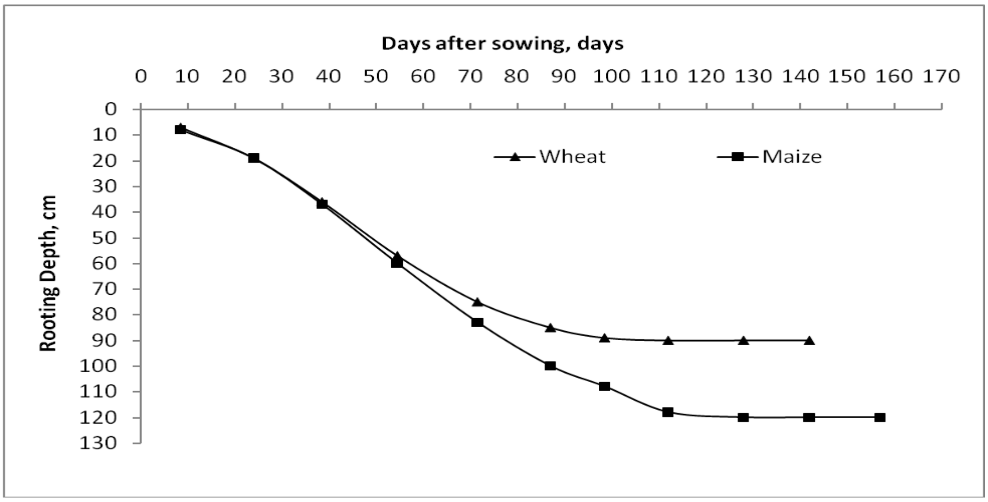

Fig. 3: Simulated rooting depth of wheat and maize

Temporal and Spatial Variation of Soil Moisture

The temporal variations of profile wise soil moisture in the root zone of wheat and maize crops have been presented in Fig.4 and Fig. 5. These figures revealed that the soil moisture experienced temporal variation in all the soil layers irrespective of the type of crops. The amplitude of variation was higher in upper layers than in lower layers. The root zone water storage ranged between 28.2 to 31.87 % volumetric moisture content (VMC) in 0-30 cm, 34.88 to 37.53 % volumetric moisture content (VMC) in 30-60 cm and 39.29 to 40.09 % volumetric moisture content (VMC) in 60-90 cm soil profile of wheat crop.

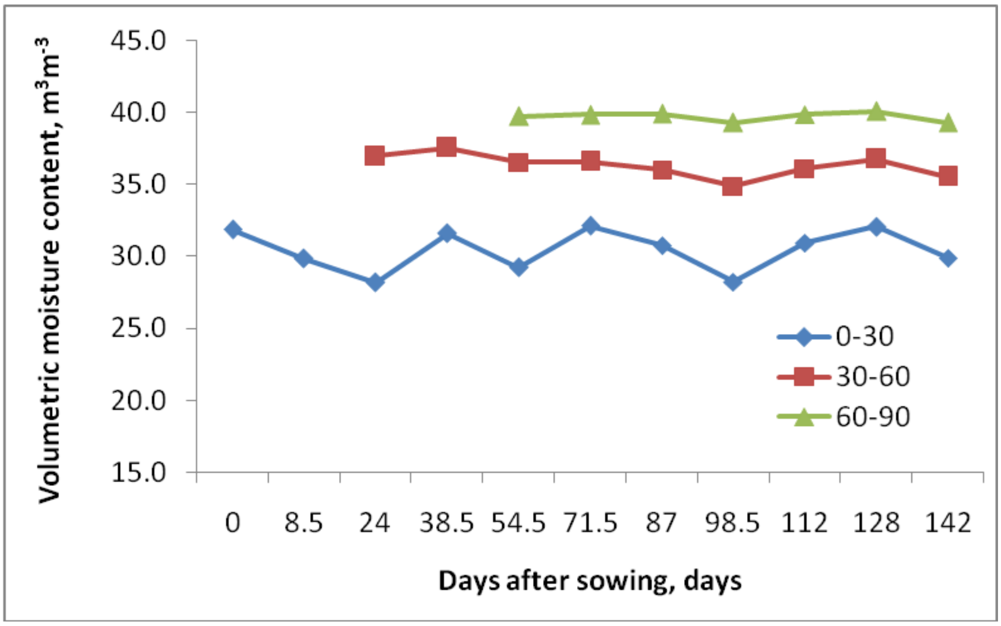

Fig 4: Temporal variation of profile soil moisture in the root zone of wheat

The trend as seen in Fig. 4 implied that the plants did not extract much moisture from 60-90 cm soil profile as the soil moisture varied only between 39.29 to 40.09 % VMC in wheat. Besides light shower of precipitation of 4.0 and 3.5 cm during the period of 47-63 DAS and 64-80 DAS, required amount of irrigation water was provided at 46, 80, 94,121and 135 DAS in wheat which caused increase in moisture level of soil profile upto field capacity. A decline in soil moisture was also observed after withdrawal of irrigations. However, the decline rate from 60-90 cm soil profile was lower than the upper layers. It is inferred from Fig.5 that volumetric moisture content ranged between 27.23 to 31.78 % VMC in 0-30 cm soil profile, 34.28 to 38.18 % VMC in 30-60 cm, 39.28 to 40.0% VMC in 60-90 cm soil profile and 41.32 to 41.40 % VMC in 90-120 cm soil profile of maize crop which showed not much variation in lower soil profile. Besides light shower of precipitation of 4.0 and 3.5 cm during the period of 47-63 DAS and 64-80 DAS, required amount of irrigation water was provided at 31, 63, 80,103,121, 135 and 149 DAS in case of maize which caused increase in moisture level of soil profile upto field capacity.

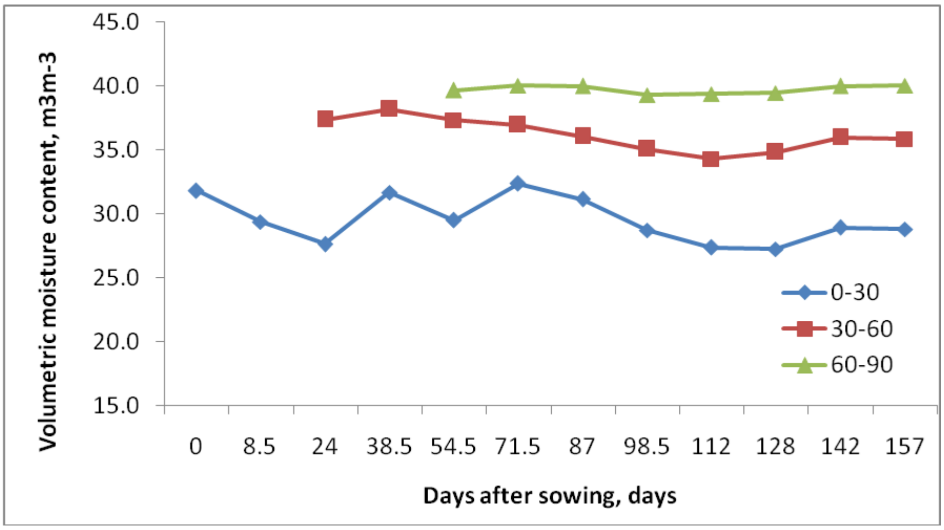

Fig 5: Temporal variation of profile soil moisture in the root zone of maize

A decline of soil moisture was observed upto 60-90 cm soil profile in maize. However, the rate of decline was lower as compared to 0-30 and 30-60 cm soil profile. The cyclic variation of root zone water storage was found to be negligible (39.28 to 40.0% VMC) in 60-90 cm soil profile in maize crop also. When irrigations were withdrawn, a slight decrease in soil moisture storage was noted in this layer in case of maize crop which was due to change in soil water storage below the root zone from both the downward flux due to drainage and upward flux due to capillary rise induced by evaporation.

A comparison of temporal variation of soil moisture of wheat and maize crop plots revealed that there was a rapid decline of soil moisture in 0-30 cm soil profile whereas the lower layers of 30-60 and 60-90 cm soil profiles exhibited a gradual decline in soil moisture during all the growth periods. The rate of decline was lower towards the lower layers. The 90-120 cm soil profile was not significantly affected by depletion in maize and the rate of depletion was also not prominent in later growth periods. Intermittent rise in the moisture content in 0-30 cm soil profile above the field capacity were observed when irrigation /rainfall occurred and resulted in excess storage of water in the uppermost soil profile (0-30 cm) as well as in 30-90 cm root zone. However, the rate of increase of profile soil water content was lower towards lower soil profiles. The soil profile (30-90 cm) below the root zone remained unaffected due to light shower of precipitation of 4.0 and 3.5 cm during the period of 47-63 DAS and 64-80 DAS in both wheat and maize. A continuous sharp decline of soil moisture in all soil profiles were observed in wheat as well as maize after the period of irrigation/ rainfall. High amplitude of variation of moisture extraction was noted in all soil profiles of the root zone of maize due to the lower time span of irrigation schedule compared to wheat. Reicoskg and Deaton (1979) [9] observed that during stress period, water extraction by crops was more from lower layers. Yadav *et al.* (2009) [10] in their study developed soil moisture flow model with water uptake by plants (wheat) under varying soil and moisture conditions and reported similar findings.

Profile wise soil moisture extraction pattern

The contribution of profile wise water uptake made by calculating change in soil moisture content in different growth periods of wheat and maize have been presented respectively in Fig.6 and Fig.7. It is inferred from figures that the soil water was extracted from all the layers of both the crops root zone but initially extraction was limited from 0-30 cm only upto 45 DAS. Fig. 6 indicated that no water uptake occurred from 90-120 cm profile in wheat crop.

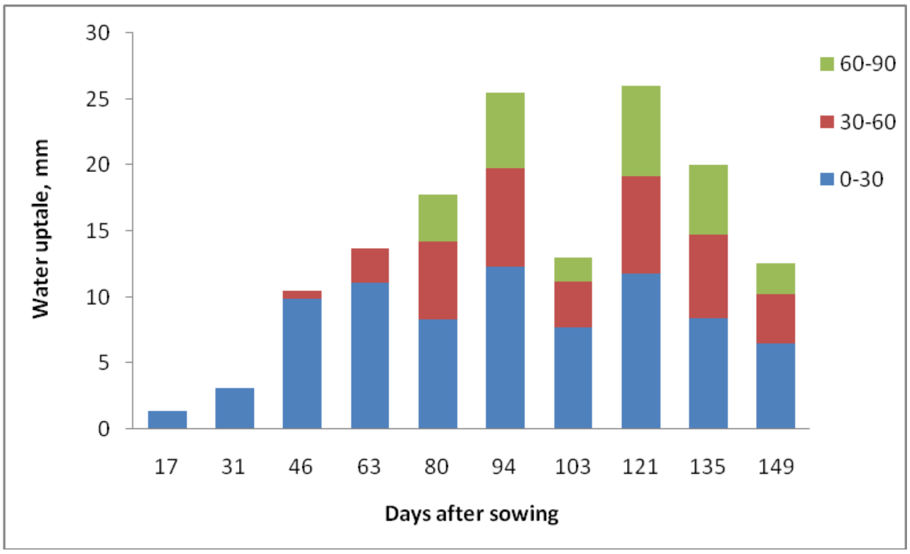

Fig 6: Periodical contribution of profile wise water uptake by wheat crop

All soil profiles exhibited variation in moisture uptake with considerably low amplitudes in the lower layers as compared to those observed in upper layers throughout the crop growth period. Grimes *et al.* (1975) [11] also found that plant water uptake is directly proportional to the rooting density. A similar trend of soil water depletion was observed in maize (Fig.7)

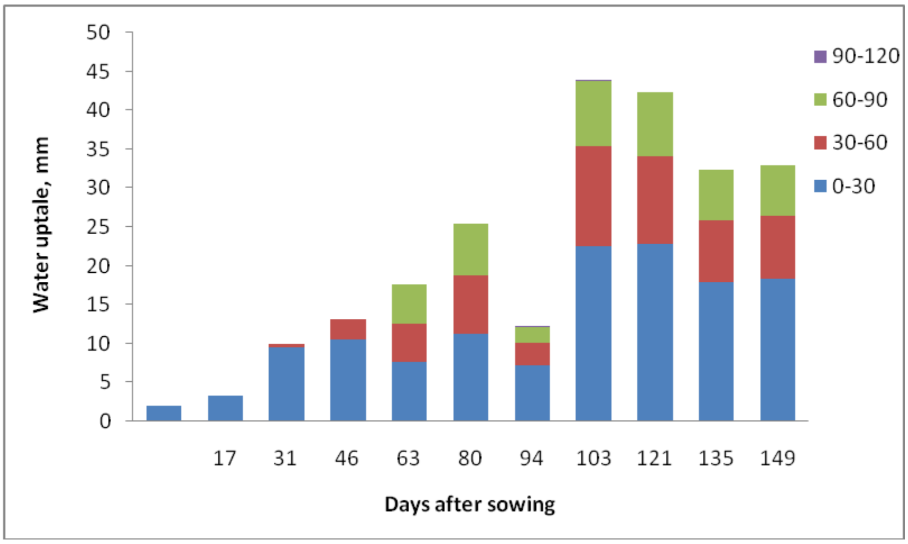

Fig 7: Periodical contribution of profile wise water uptake by maize crop

Since the plant roots were developed enough after sowing and penetrated deeper in search of water when there was not adequate water in the upper soil layers, the soil water was extracted from 30-60 (46 DAS) and 60-90 cm soil profiles (80DAS) in case of both wheat and maize crop whereas in maize, an insignificant amount of contribution was also found from 90-120 cm profile from 103 DAS to the end of growth period of maize. Soil water depletion by both the crops exhibited a trend of increased water extraction from successively deeper layers as the season progressed and the results are in conformity with the findings of Moroke *et al.* (2005) [12].

However, the magnitude of contribution from 30-90 soil profiles was low initially as compared to 0-30 soil profiles. The depth variation of moisture within 60 cm soil profile was greatly influenced by the increasing crop water extraction in later growth periods. As observed from the experiments, the 60-90 cm soil profile tended to remain almost steady upto the last irrigation event and it is also obvious that the plants extracted most of the soil moisture from 0-60 cm soil profiles in case of wheat and maize crops and findings are in conformity with Imtiyaz *et al.* (1982) [13]. Therefore, it is inferred that only 0-60 cm of soil profile should be considered for scheduling of irrigation for wheat and maize crop grown in sandy loam soil in the sub-tropical regions. Chaudhary *et al.* (1975) [14], Chaudhary and Singh (1990) [15] and Sharma and Ghildyal (1977) [16] also reported that the depth and extent of profile water depletion depend on crop root distribution, growing period as well as stress conditions.

The soil moisture extraction pattern from the soil layers 0-30, 30-60 and 60-90 cm for wheat and upto 120 cm for maize have been presented in Fig.8 from which it is obvious that water uptake from the 0-30 cm soil depth amounted to 80.5 mm (56.1 percent) and 133.3 mm (56.1 percent) of the total profile water use of 143.5 and 235.6 mm for the respective crops.

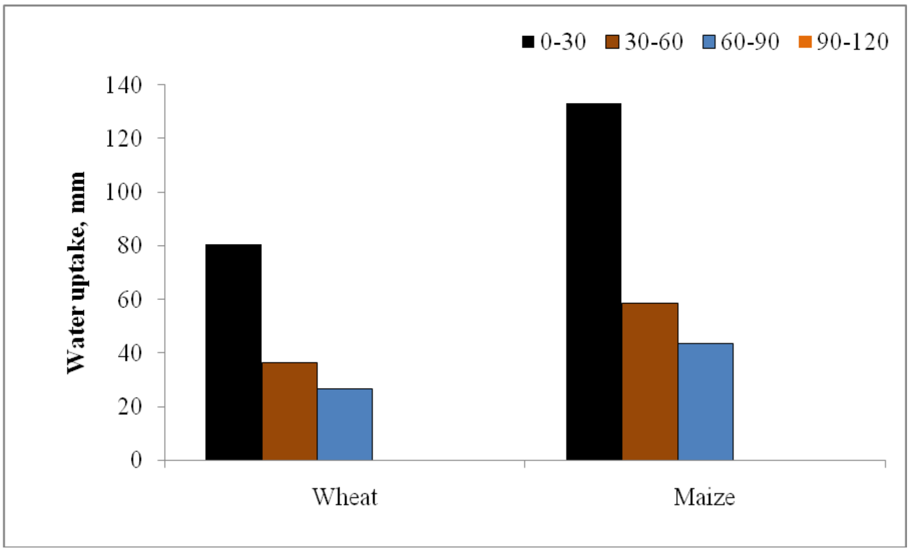

Fig 8: Profile wise soil moisture extraction pattern of wheat and maize

Soil moisture extraction decreased as the soil depth increased and it was 36.4 mm (25.4 percent) and 58.5 mm (24.8 percent) from 30-60 cm soil depth whereas from 60-90 cm soil profile, water uptake was reported to be 26.6mm (18.5 percent) and 43.6 mm (18.5 percent) for wheat and maize, respectively. Michael (1999) [17] in his study reported 40, 30, 20 and 10 percent soil moisture extraction from each quarter (25 percent) of crop root zone depth from upper to lower soil profiles. The amplitude of the variation was more in upper soil profile mainly due to the evaporation from the soil surface. Islam (1991) [18] also reported that a maximum percentage of soil moisture depleted from the top most 25 percent soil layer by the non-irrigated as well as the irrigated treatments of two years in which around 50 percent of the total water used was depleted from top layer.

Fig.9 show temporal variation of moisture extraction rate of wheat and maize which indicated the similar trend of variation in initial growth stage but in later stage moisture extraction rate was found greater in case of maize crop. Average moisture extraction rate for the respective crops were calculated as 1.0 and 1.36 mm day^{-1}.

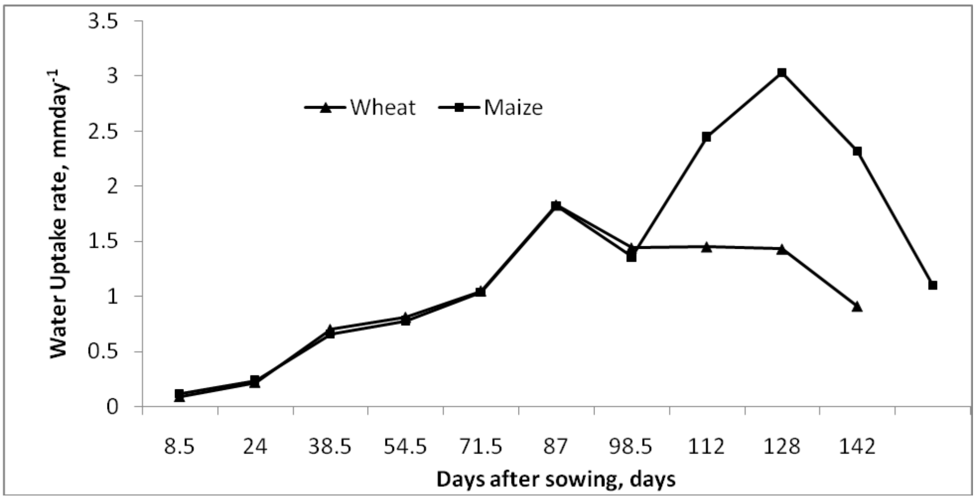

Fig 9: Temporal moisture extraction rate of wheat and maize

Crop water use efficiency

Crop water use efficiency has been calculated as ratio of crop yield and quantum of seasonal water depleted by the crops in the process of evapotranspiration and the results of the study revealed that the water use efficiency was lower in case of maize (14.89 kg.ha^{-1} mm^{-1}) in comparison to wheat crop (22.67 kg.ha^{-1} mm^{-1}).

Conclusions

According to the findings of the experiment, it is recommended that under water scarcity condition, when soil water stress is imposed during non-critical stages of growth, irrigation is to be scheduled for wheat and maize crop grown in sandy loam soils in sub-humid regions. The plants extracted most of the soil moisture from 0-60 cm soil profile in case of wheat and maize crops. Therefore, 0-60 cm of soil profile is to be considered for scheduling of irrigation water for wheat and maize crop grown in these regions under water scarcity conditions and keeping in view depletion of available soil water, irrigation is to be maintained in 0-60 cm soil profile to obtain high values of yield parameters with less water use.

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