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Water management of cabbage (*Brassica oleracea*) under stressed conditions

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Abstract
The process of scheduling irrigation aims to figure out the right amount and timing of water application to accomplish desired crop production and quality, optimize water conservation and limit any potential adverse effects on the environment, like nutrient leaching below the crop root zone. The study was carried out at the experimental site of Vegetable Research Centre of G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India. Soil moisture content was estimated using gravimetric method periodically in 0-15, 15-30, 30-45 and 45-60 cm soil profiles. Field experiments were conducted on cabbage crop (*Green Coronet*) during 2020-2021 and 2021-2022. Five irrigation treatments were maintained based on the maximum allowable depletion (MAD) of available soil water. Field experiments showed that irrigation schedule with 45% maximum allowable depletion of available soil water gives the maximum water use efficiency for cabbage crop. It was found that for scheduling of irrigation for cabbage crop 0-30 cm soil profile should be considered as most of the water was found to be extracted from this layer by the plant.

Keywords: Water management, cabbage, *Brassica oleracea*, stressed conditions

Introduction
Water stress that can affect crop yields is generally avoided through irrigation scheduling, which is the scientific process of deciding on and optimising the timing and volume of irrigation applications to achieve certain management goals. Currently there are about 250 million hectares of irrigated land worldwide, most of which utilise surface irrigation. Because of only making up 17% of all agricultural area, irrigated land produces 36% of the world's total food requirement (Kashyap and Panda, 2002) [7]. The irrigation needs of the entire cropping pattern cannot always be properly addressed when there is a lack of water. Deliberate under irrigation, also known as deficit irrigation can be extremely important in certain conditions (Jehan *et al*., 2022) [6]. By the deficit irrigation, crops are purposefully under irrigated during plant growth stages that are relatively insensitive to water stress as regards to the quality and quantity of the harvested yield (Musick 1994) [9]. Identifying growth stages of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling for both maximum crop yield and most efficient use of scarce water resources (Doorenbos and Kassam, 1979) [3].

Cabbage is one of the most popular winter vegetables grown in India. Present production in India is about 9.56 million metric tons from 0.412 million hectare area and average productivity of 23.203 metric tons/hectare (http://www.fao.org, 2023). It thrives well in all soil textures that have good internal drainage (Iqbal *et al*., 1999) [5]. It is relatively sensitive to soil water deficits. Cabbage needs frequent irrigations for it a good growth and yield (Gautam *et al*, 2013; Beshir, 2017; Roti *et al*., 2018) [14, 1, 10]. With these background considerations a comprehensive field investigation was undertaken on crop cultivar *Green Coronet* of cabbage. The effect of various scheduling of irrigation on the profile soil water status, crop yield and water use efficiency were studied. Irrigation schedules were based on 15, 30, 45, 60 and 75 maximum allowable depletion (MAD) of available soil water (ASW). The major goal of the study was to investigate the effect of scheduling of irrigation on profile soil water status, Yield and water use efficiency of cabbage crop.

Materials and Methods
The reported study was carried out at the experimental field of the G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India. The field is located on Vegetable Research Centre, Pantnagar district Udham Singh Nagar, India is situated at 29.02° N and

79.49° E latitude with an altitude of 244 m above the mean sea level. The climate is typically humid sub-tropical. The maximum temperature reaches up to 44 °C in the summers and drops down to 1.5 °C in the winters. The average rainfall in this area is about 1350 mm per annum. Most of which generally occur during June to middle of September. The physical properties of the soil of experimental crop field used for cabbage crop are given in Table 1. Field experiments were conducted on Cabbage crop which belongs to the family *Brassicaceae*, genus *Brassica* and species *Brassica oleracea*. The cultivar *Green Coronet* was selected, which is popular 90-120 days vegetable crop of the locality and suits to the prevailing climate of the region. Water deficit during the period of Head initiation have the greatest adverse effect on yield, whereas early vegetative and maturation periods are less sensitive (Doorenbos and Pruitt, 1977) [2].

Table 1: Physical property of various soil profiles of the experimental crop field

Soil depth (cm)	Particle size Distribution (%)			Bulk density (g/cc)	Saturated hydraulic conductivity (cm/day)
	Clay	Silt	Sand		
0-15	11.96	29.91	58.14	1.52	2.03
15-30	13.62	28.49	57.88	1.50	1.63
30-45	12.01	30.06	57.93	1.53	2.02
45-60	12.66	25.35	61.98	1.56	1.84

The first Experiment was conducted during the period of 28th October, 2020 to 25th February, 2021. The second Experiment was conducted during the period of 3rd November, 2021 to 24th February, 2022.

Field layout and Experimental details

Cabbage was growing in a surface land of 100 m^2 area. The field was divided into 20 plots of 2m x 2m size. Farm yard manure (FYM) was manually with top 10 cm of soil layer at the rate of 20 kg/ha 10 days before transplanting. Second dose of FYM was applied at the time of head initiation (approximately 30 days after transplanting) at the rate of 10 kg /ha. The transplanting was done at a spacing of 60 cm, row to row and also 60 cm plant to plant during both crop seasons.

Irrigation treatments and scheduling

The irrigation treatments during cabbage growing experiments consisted of irrigation scheduling based on maximum allowable depletion (MAD) of available soil water (ASW) criteria, which is given as (Kashyap and Panda, 2003) [8]

T_1 = 15% maximum allowable depletion (MAD) of available soil water (ASW)
T_2 = 30% MAD of ASW
T_3 = 45% MAD of ASW
T_4 = 60% MAD of ASW
T_5 = 75% MAD of ASW

Irrigation scheduling was based on the percentage depletion of available soil water in the root zone. The available soil water was taken as the difference between root zone water storage at field capacity and permanent wilting point. For estimating water storage the effective root zone of Cabbage crop was considered as 45 cm, irrespective of growth stage. Using the data of soil moisture measured by gravimetrically, the percentage depletion of available soil water in the effective root zone was estimated. The plots were irrigated using a hosepipe and the water meter to give the exact volume of water.

Data collection

In order to study water balance, crop response to deficit irrigation and water use efficiency, it was necessary to collect data on profile soil moisture content and the growth attributes of the crop under consideration. In order to assess the change in the soil water balance, soil moisture was measured in 0-15, 15-30, 0-45 and 45-60 cm soil profiles. The moisture content of soil layers were measured gravimetrically. Moisture measurements were made on 2-3 days interval.

Results and Discussions

In order to assess the depth and time variation of soil moisture under different scheduling of irrigation, soil moisture was measured periodically in 0-15, 15-30, 30-45 and 45-60 cm soil profiles during both the experiments.

Depth and Time variation of soil moisture

The temporal variations of soil moisture in the root zone and below the root zone of the experimental cabbage crop are presented in fig. 1. The figure shows that soil moisture experienced a cyclic temporal variation at all soil depths. This trend was observed irrespective of the level of irrigation (MAD level). The amplitude of this cyclic variation (Fig. 1) was higher in upper layer than the lower layers. In experiment 1, there was a rapid decline of soil moisture in 0-15 cm soil profile 92 days after transplanting (DAT) to the end of growth period. The lower layer of 15-30, 30-45 and 45-60 cm soil profile also exhibited a gradual decline in that order up to the end of the growth period, the decline was quite slow in 45-60 cm soil profile. The amplitude of cyclic variation was more in 0-15 cm soil profile because most of the applied irrigation water was lost through the evaporation from the soil surface beside the transplantation. In addition to this, a portion of the applied irrigation water percolated to the lower layers also. Since the frequency of irrigation was high under T_1, plants extracted more water from the upper layers. Therefore, 15-30, 30-45 and 45-60 cm soil profiles did not exhibit much cyclic variation. This trend was observed in both the experiments.

In resemblance to the temporal variation of soil moisture under T_1, soil moisture in 0-15, 15-30, 30-45 and 45-60 cm soil profiles under 30% MAD (T_2) also exhibited cyclic pattern. The results are presented in Fig. 2. Continuous sharp declines of soil moisture in all soil profiles were observed on 92 DAT. The magnitude of cyclic variation was higher in 30-45 and 45-60 cm soil profiles as compared to similar layers of T_1 during both the crop seasons.

High amplitude of cyclic variation was noted in all soil profiles of the root zone under 45% MAD (T_3). Since the irrigations were scheduled at 45% MAD, the plant roots penetrated deeper in search of water as it was not adequate in the upper soil layers. The temporal variation of soil water was observed to be similar during both the experiments. The temporal variation under T_3 exhibited cyclic pattern upto 90 DAS in 0-15 and 15-30 cm soil profiles during experiment 1, while 30-45 and 45-60 cm soil profiles showed a gradual decline on 72 DAT. A similar trend was observed during other experiment also (Fig. 3).

Considerable soil moisture fluctuation was observed under 60% MAD (T_4) schedule. All soil profiles exhibited discernible cyclic variation, with considerably low amplitudes in the lower depths as compared to those observed at upper depths. This was ascribed to the large volume of water applied at a time during irrigation which shown in Fig 4.

The 45-60 cm soil profile tended to remain steady upto the last irrigation applied, after which it decreased only marginally during the remaining growth period. Soil moisture below the root zone (45-60 cm soil profile) of the experimental plots experienced minimum cyclic variation with time. A slight continuous decline was observed when irrigations were discontinued. This trend was observed during both experiments.

Crop water use efficiency

The crop water use efficiency was taken as the ratio of the fresh yield and the crop evapotranspiration. The results pertaining to water use efficiency of the cabbage crop under different scheduling of irrigation during crop experiments 1 and 2 are presented in Table 2. It is evident from the table that the highest crop water use efficiency was attained when the irrigation was scheduled at 45% depletion of ASW (T_3). A rising trend of crop water use efficiency was noticed from T_1 to T_3 and after that it decreased for T_4 and T_5 as the irrigations were delayed. A similar trend was observed during both crop seasons.

Field water use efficiency

The field water use efficiency was estimated in terms of fresh yield obtained per unit of land used and per unit of water available to the field. The results shown in Table 2 revealed that the highest field water use efficiency was attained when the irrigation was scheduled at 45% depletion of ASW (T_3).

Table 2: Water use efficiency (WUE) of Cabbage crop under different scheduling of irrigation during experiments 1 and 2.

Experiment No.	Treatments	Fresh head yield (kg/ha)	ET (mm)	Irrigation (mm)	Crop-WUE (kg/ha/mm)	Field-WUE (kg/ha/mm)
1 (2020-21)	T1	29313	240.2	492	122.04	59.58
	T2	27978	227.82	329	122.81	81.70
	T3	26225	212.37	283	123.49	90.01
	T4	23497	209.2	272	112.32	84.99
	T5	20978	202.9	267	103.39	73.87
2 (2021-22)	T1	27938	236.28	332	118.24	82.80
	T2	26244	224.40	302	116.95	86.90
	T3	24478	205	251	119.40	96.22
	T4	22411	203	248	110.39	90.37
	T5	19845	189.58	259	104.68	75.00

Similar to crop water use efficiency, a rising trend of field water use efficiency was noticed from T_1 to T_3 after that it decreased for T_4 and T_5 as the irrigations were delayed. This trend was same during both crop seasons. Field experiments conducted during both crop seasons revealed that irrigation schedule.

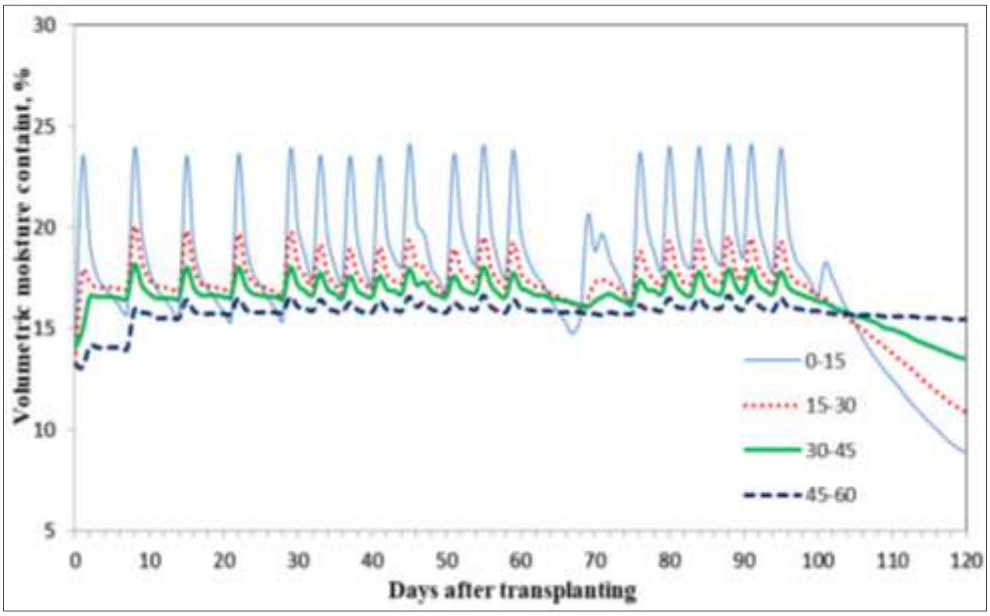

Fig 1a: Temporal variation of soil moisture in cabbage crop root zone at 15% MAD (T1) of available soil moisture during experiment 1

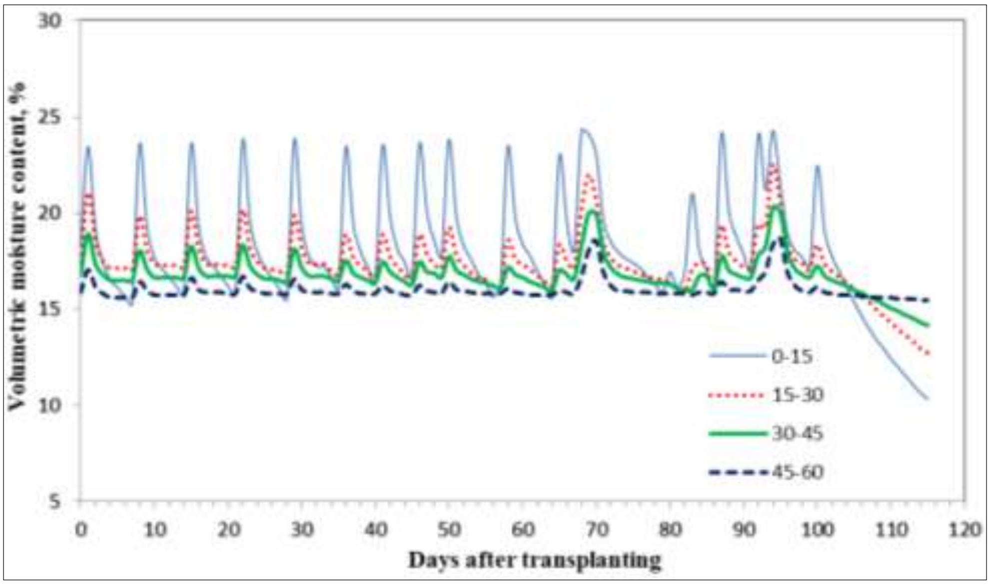

Fig 1b: Temporal variation of soil moisture in cabbage crop root zone at 15% MAD (T1) of available soil moisture during experiment 2.

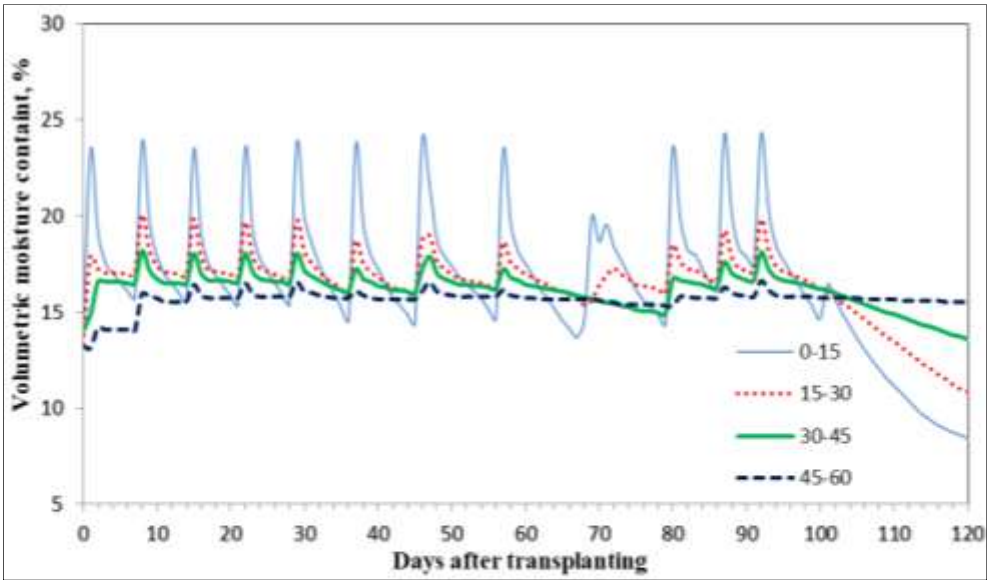

Fig 2a: Temporal variation of soil moisture in cabbage crop root zone at 30% MAD (T2) of available soil moisture during experiment 1

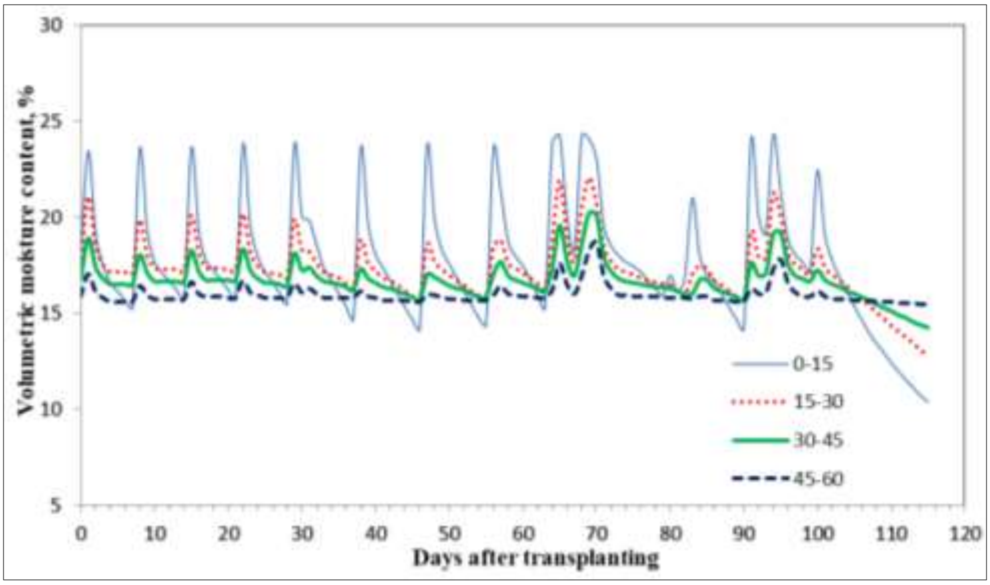

Fig 2b: Temporal variation of soil moisture in cabbage crop root zone at 30% MAD (T2) of available soil moisture during experiment 2

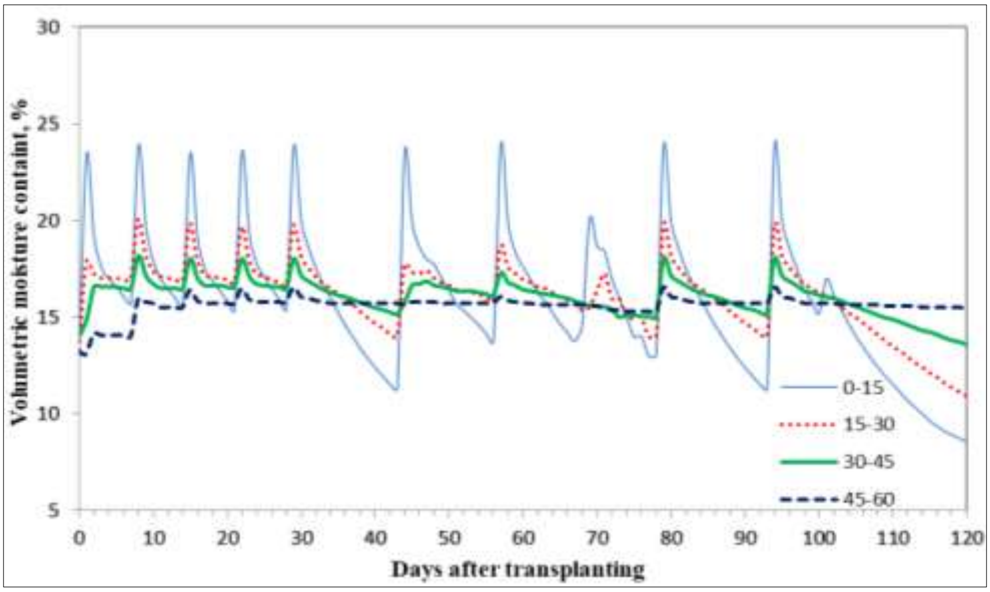

Fig 3a: Temporal variation of soil moisture in cabbage crop root zone at 45% MAD (T3) of available soil moisture during experiment 1

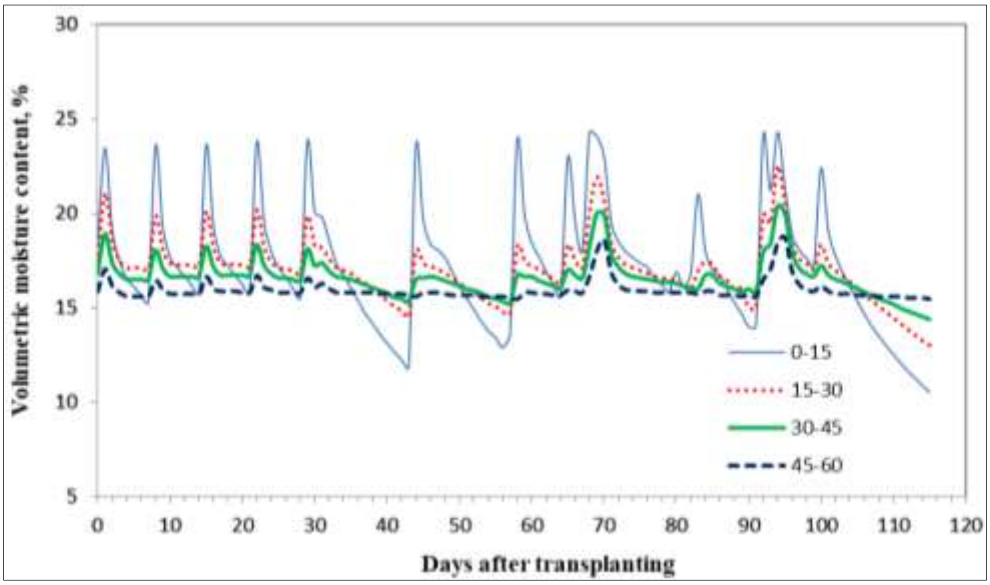

Fig 3b: Temporal variation of soil moisture in cabbage crop root zone at 45% MAD (T3) of available soil moisture during experiment 2

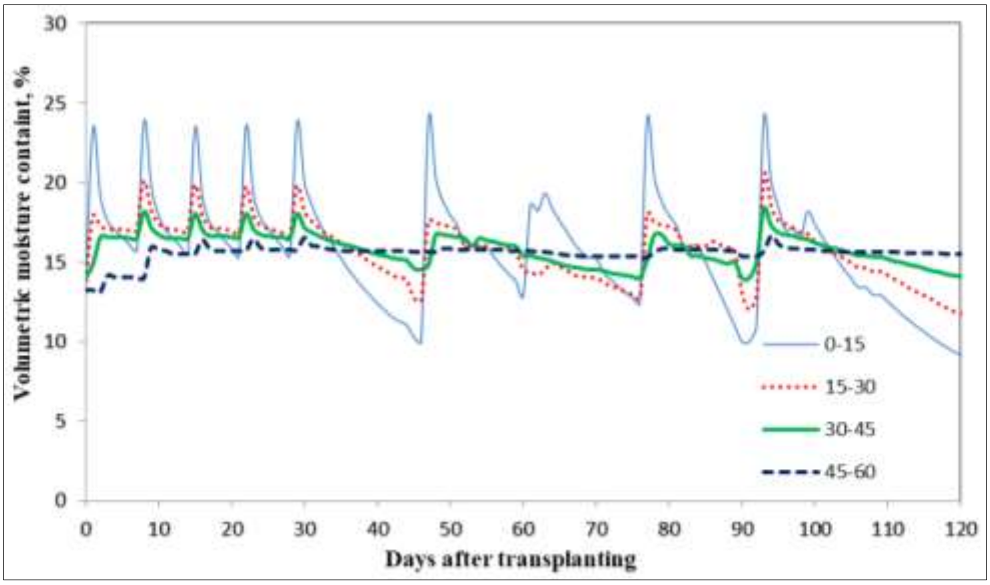

Fig 4a: Temporal variation of soil moisture in cabbage crop root zone at 60% MAD (T4) of available soil moisture during experiment 1

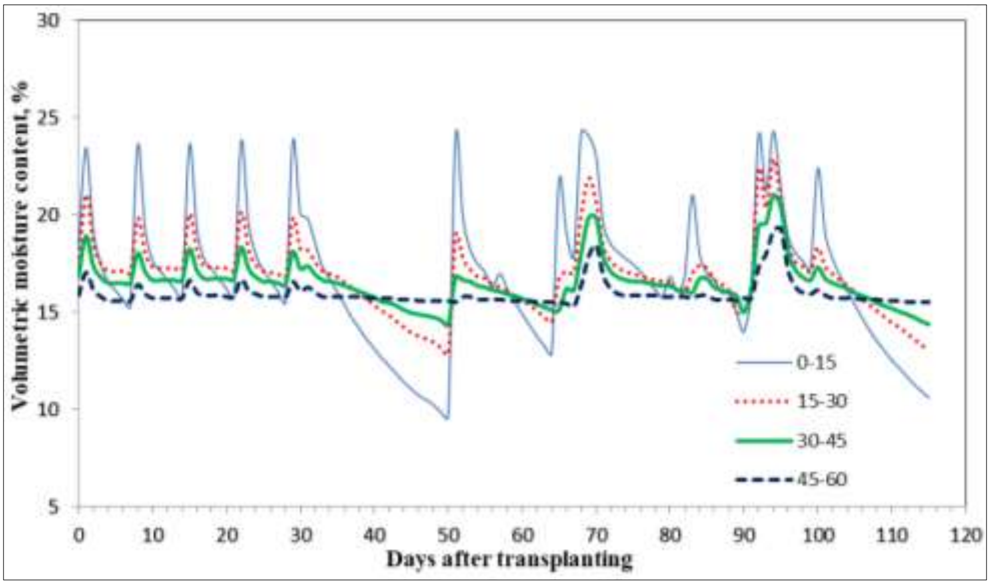

Fig 4b: Temporal variation of soil moisture in cabbage crop root zone at 60% MAD (T4) of available soil moisture during experiment 2

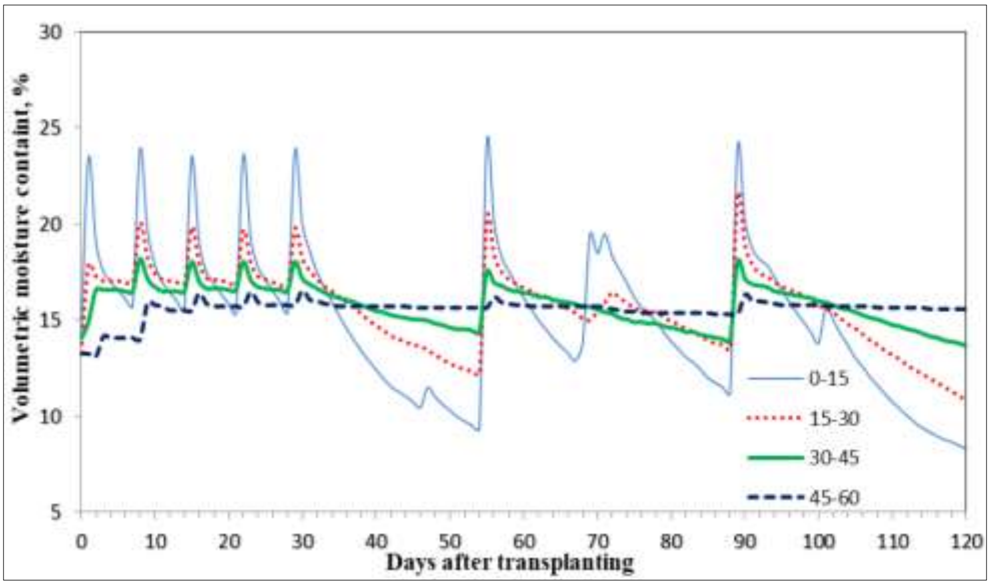

Fig 5a: Temporal variation of soil moisture in cabbage crop root zone at 75% MAD (T5) of available soil moisture during experiment 1

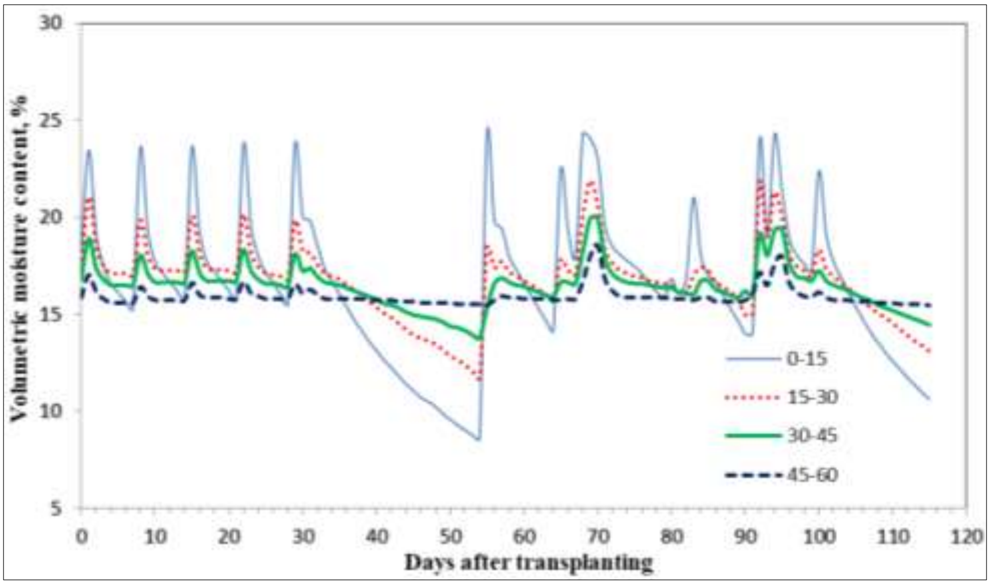

Fig 5b: Temporal variation of soil moisture in cabbage crop root zone at 75% MAD (T5) of available soil moisture during experiment 2

Conclusions

The results of the study revealed that under water scarcity conditions, when soil water stress is imposed during non-critical stages of growth, irrigation is to be scheduled at 45% maximum allowable depletion of available soil water for cabbage crop grown in sandy loam soils in a sub-tropical humid region. A soil water stress of 45% MAD gives the highest crop water use efficiency as well as field water use efficiency. Only 0-30 cm of soil profile is to be considered for scheduling of irrigation for cabbage crop grown in sandy loam soils, since most of the water used by the crop is extracted from this layer.

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