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Water management for Chilli (*Capsicum annuum* L.) crop in sub-tropical humid region

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***Abstract*— *Irrigation scheduling is determining the amount of water to be applied and when to achieve desired crop production and quality, to maximize water conservation, and to limit any adverse effects that may be experienced by the environment, such as the leaching of nutrients beneath the root zone of the crop. The study was carried out at the experimental site of Vegetable Research Centre (VRC) of G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India, to investigate the effect of different soil moisture regimes on the yield of chilli crops and growth parameters related to irrigation scheduling. Also, as part of the study, it was determined the minimum irrigation amount that needs to be provided in order to achieve significant returns for the crop, along with recommended guidelines for measuring soil moisture status. Four Treatments of irrigation that of four different Maximum allowable depletion (MAD) levels at 20% (T_1), 40% (T_2) 60% (T_3) and 80% (T_4) were taken for this study. Soil moisture content was estimated using gravimetric method periodically in 0-20, 20-40, and 40-60 cm soil profiles. Field experiments were conducted on chilli (also known as chilli pepper) during 2021-2022. Four irrigation treatments were maintained based on the maximum allowable depletion (MAD) of available soil water. Field experiments showed that irrigation schedule with 40% (T_2) maximum allowable depletion of available soil water gives the maximum water use efficiency while the highest yield was obtained as 7624 kg/ha (T_1) for chilli crop. It was also found that for scheduling of irrigation for chilli crop, 0-20 cm soil profile should be considered as most of the water was found to be extracted from this layer by the plant.*

Keywords*— Available soil moisture, Irrigation scheduling, Chilli, Stress conditions, Water management, Water use efficiency, Yield attributes.

I. INTRODUCTION

A study on irrigation scheduling for chilli (also known as chilli pepper) cultivation would typically focus on determining the most efficient and effective timing and amount of water to apply to the plants. This is crucial for maximizing yield, quality, and resource use efficiency. Water scarcity is a pressing concern in agricultural regions worldwide, prompting the need for sustainable water management strategies to optimize crop production while conserving this precious resource (McLaughlin and Kinzelbach 2015). Also, rainfall is a source that help to reduce water scarcity (Singh et al. 2023a; Singh and Kumar 2021). The various researchers worked on this rainfall parameter to quantify trend, variability, and modelling, etc (Singh et al. 2024; Singh et al. 2023b; Yadav et al. 2022; Singh and Kumara 2021; Yadav et al. 2020). Among crops grown in diverse climates, chilli (Capsicum annuum L.) stands out as a vital commodity globally, valued for its culinary, economic, and nutritional significance. However, the cultivation of chilli demands substantial water inputs, making it susceptible to water stress and exacerbating water scarcity issues (Yadav et al. 2023). The efficient use of water in chilli cultivation is imperative for mitigating environmental impact and ensuring agricultural sustainability (Abdelkhalik et al. 2020). One approach to address this challenge is through the implementation of different water application schedules, which regulate the timing and quantity of water supplied to the crop. By strategically managing irrigation, farmers can optimize water use efficiency, minimize wastage, and enhance crop yields (Kashyap, and Panda, 2001; Panda et al. 2004; Singh et al. 2023c). An investigation has been carried out to determine whether irrigation scheduling can help to increase yields and growth parameters of chilli crops in relation to different soil moisture regimes and the minimum amount of irrigation that should be provided so that significant returns can be obtained from the crop, as well as the identification of simple guidelines for determining the moisture status of the soil, is the objective of this study (Khalkho et al. 2013). Understanding the effect of various water application schedules on water conservation and yield of chilli crops is crucial for informing sustainable agricultural practices. This research aims to investigate the impact of different irrigation regimes on water usage, soil moisture retention, and ultimately, chilli yield. By examining the interactions between water application schedules and crop performance, valuable insights can be gained into optimizing water management strategies for chilli cultivation.

One of the most important vegetables in the world is the chilli pepper (Capsicum spp.) which plays a key role in our daily lives. In almost all parts of the country, it is grown and its growing period of 110 to 150 days and it varies from place to place. Chilli originated from Americas with their cultivars now growth around the world because they are widely used as food, medicine and Indian kitchens for their spicy taste. Pepper (capsicum spp. Capsicum annum and capsicum frutescens) belonging to the family of 'Solanaceae is a crop plant and it is grown in different varieties for the purpose of growing vegetables, spices, condiments, sauces, and pickles. The most important chilli growing states in India are Telangana, Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu, which together constitute nearly 75percent of total cultivated area under chilli production.

II. MATERIALS AND METHODS

The 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, (VRC) Pantnagar district Udham Singh Nagar India (Fig.1). It 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. Summer temperatures can reach up to 44 to 45 degrees Celsius, while winter temperatures can drop to 1.5 degrees Celsius during the winter season. There is usually around 1350 mm of rain per year in this area. It was generally observed that most of the rain takes place in the months of July to September. The physical properties of the soil used in the experimental crop field for chilli production are given in Table1. Field experiments were conducted on chilli crop which belongs to the Solanaceae family, which is a popular 110-150 days vegetable crop of the locality and suits to the prevailing climate of the region. Water deficit during the period of pod initiation have the greatest adverse effect on yield, whereas early vegetative and maturation periods are less sensitive. The field experiment was undertaken during the period from 26 November 2021 to 15 May 2022.

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

Soil depth (cm)	Particle size distribution (%)			Bulk density (g/cm3)	Saturated hydraulic conductivity (cm/h)
	Clay	Silt	Sand		
0-20	12.25	30.56	58.75	1.48	2.15
20-40	13.42	27.80	56.90	1.52	1.95
40-60	11.5	29.50	60.82	1.58	1.68

Field layout and Experimental details:

An area of 100 square meters of surface land was used for growing chilli crop as part of a surface farm. The field was divided into 20 plots of equal dimensions of 2m by 2m. The farm yard manure (FYM) was manually applied to the top 12 cm of the soil layer at a rate of 25 kg/ha 1 week before transplanting on the farm. Second dose of FYM was applied at the time of the fruiting (approximately 45 days after transplanting) at the rate of 12 kg /ha. The transplanting was done at a spacing of 60 cm from row to row as well as 60 cm from plant to plant.

Irrigation treatments and scheduling:

A variety of irrigation treatments were used during the chilli crop growing experiments, including irrigation scheduling based on maximum allowable depletion (MAD) of available soil water (ASW) criteria, which is given as (Kashyap and Panda, 2003), (Kashyap and Anita 2023).

1. T_1 = 20% maximum allowable depletion (MAD) of available soil water (ASW)
2. T_2 = 40% MAD of ASW
3. T_3 = 60% MAD of ASW
4. T_4 = 80% MAD of ASW

The irrigation scheduling was based on a calculation of the percentage of soil water depletion in the root zone of the plant. In this study, soil water availability was determined as the difference between the root zone water storage at field capacity and permanent wilting point of the plants. For estimating water storage, the effective root zone of Chilli crop was considered as 40 cm, irrespective of growth stage. A percentage depletion of available soil water in the effective root zone of the Chilli crop has been estimated using data of soil moisture measured by gravimetric measurements. There was a water meter attached to the hosepipe to measure the exact volume of water applied to each plot, and a hosepipe to irrigate the plots.

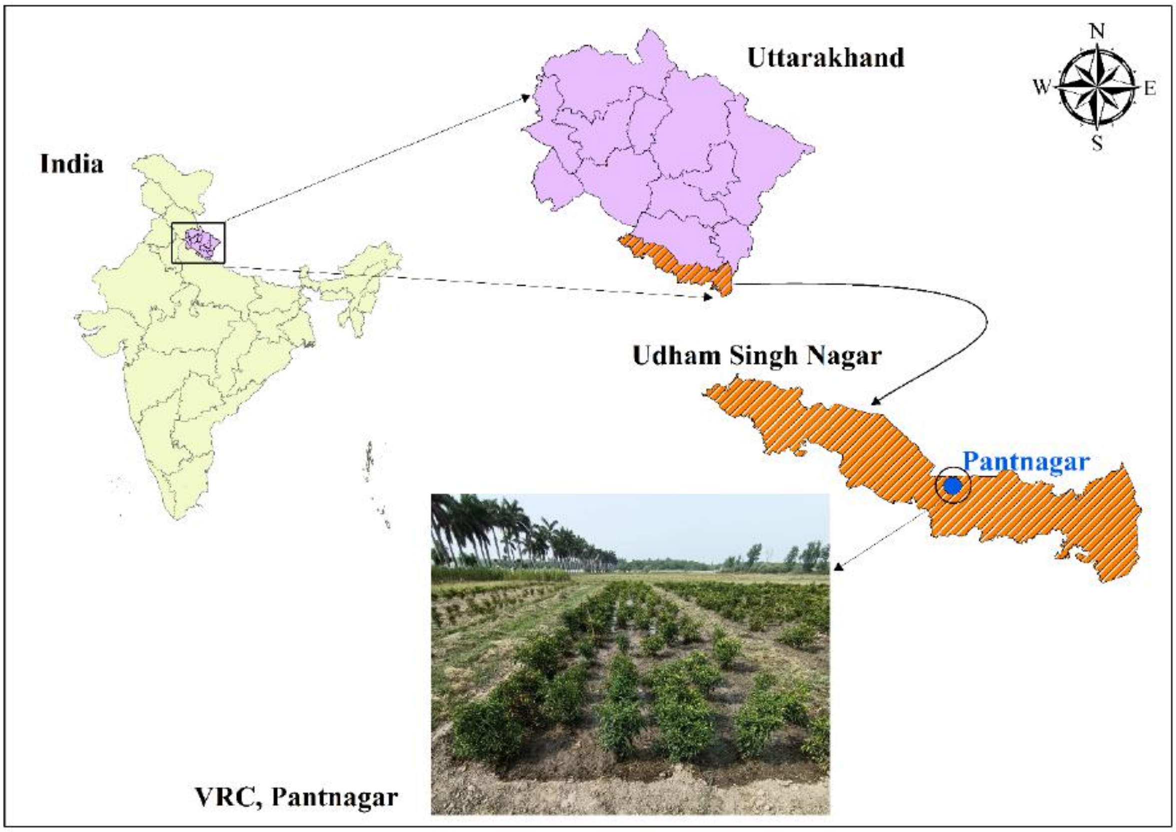

Fig.1. Study Area

Data collection:

This research was carried out in order to investigate the water balance, crop response to deficit irrigation and efficient use of water. To understand the growth attributes of the crop under consideration, data on soil moisture profile content and the characteristics of development of the crop was recorded. The moisture content of soil layers were measured gravimetrically. The moisture levels were measured every 2-3 days throughout the duration of the experiment.

III. RESULTS AND DISCUSSIONS

The study was conducted to assess how soil moisture changes with depth and time under a variety of irrigation scheduling conditions. As a part of experiments, the moisture of the soil was periodically measured at depth intervals of 0-20, 20-40, and 40-60 cm in soil profiles.

Depth and Time variation of soil moisture:

The temporal variation of soil moisture in the root zone and below the root zone of an experimental chilli crop over a period of time is presented in Fig 2 through Fig 5. There was a cyclic variation in soil moisture throughout all depths of soil shown in the Fig 2, indicating cyclic trends.

Regardless of the irrigation level (MAD level) applied to the field, this trend was observed. This figure represents the variation of volumetric soil moisture content (%) at different soil depths over time, specifically in terms of days after sowing. 0-20 cm soil depth. The moisture content at this shallow depth shows significant fluctuations over time, with sharp peaks and valleys. This suggests that the topsoil is highly sensitive to changes in environmental conditions, such as rainfall or irrigation, which quickly affect moisture levels. Towards the end of the observation period (around 160 days), there is a steep decline in moisture content. The moisture content at this intermediate depth is relatively more stable compared to the topsoil but still shows some fluctuations. The variations are less pronounced, indicating that this layer retains moisture better and is less immediately impacted by surface conditions. 40-60 cm soil depth at this deeper depth, the moisture content remains the most stable over time. The black line indicates minimum fluctuation, suggesting that this soil layer is more insulated from surface activities and retains moisture consistently. However, similar to the other depths, there is a notable decrease in moisture towards the end of the period. The overall moisture content across all depths generally decreases over time, especially after around 150 days. This could be due to the depletion of moisture in the soil as the growing season progresses, possibly due to reduced rainfall, increased plant uptake. The top layer (0-20 cm) is most dynamic, showing rapid changes in moisture levels, which indicates that it is more influenced by external factors like weather conditions. The deeper layers (20-40 cm and 40-60 cm) show progressively more stable moisture levels, with the deepest layer being the least variable. The graph highlights how soil moisture content varies significantly with depth and time, with the shallowest layer being the most variable and the deepest layer the most stable. This information can be critical for understanding how water is distributed in the soil profile and for making informed decisions about irrigation and crop management. Since the frequency of irrigation was high under T_1, plants extracted more water from the upper layers. Therefore, 20-40, and 40-60 cm soil profiles did not exhibit much cyclic variation. This trend was observed in the experiments.

A similar temporal variation of soil moisture may be found under the same conditions, soil moisture in 0-20, 20-40, and 4-60 cm soil profiles under 40% MAD (T_2) also exhibited cyclic pattern. The results are presented in Fig. 3. Continuous sharp declines of soil moisture in all soil profiles were observed on 110 DAT. The magnitude of cyclic variation was higher in 20-40 and 40-60 cm soil profiles as compared to similar layers of T_1 during the crop seasons.

The root zone soil profiles under 60% MAD (T3) showed a high level of cyclical variation in amplitude, as was observed in all soil profiles. A 60% MAD irrigation schedule may have caused root penetration deep into the soil layers because the roots had to search for more water as the upper soil layers did not have enough water available. The temporal variation of soil water was observed to be similar during the experiments. The temporal variation under T_3 exhibited cyclic pattern upto 95 DAS in 0-20 and 20-40 cm soil profiles during experiment 1, while 60 cm soil profiles showed a gradual decline on 130 DAT. A similar trend was observed during other experiment also (Fig. 4).

Considerable soil moisture fluctuation was observed under 80% 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 5.

The 40-60 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 (40-60 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 experiments.

Crop water use efficiency:

As a measure of crop water use efficiency, the ratio between the fresh fruit yield and the crop evapotranspiration was used. The results pertaining to water use efficiency of the Chilli crop under different scheduling of irrigation during crop experiments 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 40% depletion of ASW (T_2). A rising trend of crop water use efficiency was noticed from T_1 to T_2 and after that it decreased for T_3 and T_4 as the irrigations were delayed.

Field water use efficiency:

The field water use efficiency was estimated in terms of fresh fruit 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 40% depletion of ASW (T_2). Similar to crop water use efficiency, a rising trend of field water use efficiency was noticed from T_1 to T_2 after that it decreased for T_3 and T_4 as the irrigations were delayed.

Table 2. Water use efficiency (WUE) of Chilli crop under different scheduling of irrigation during experimental year

Experimental Year	Treatments	Fresh fruit yield (kg/ha)	ET (mm)	Irrigation (mm)	Crop-WUE (kg/ha/mm)	Field-WUE (kg/ha/mm)
2021-22	T1	7624	415	490	18.37	15.55
	T2	7240	375	431	19.30	16.79
	T3	6345	354	420	17.92	15.10
	T4	5023	305	351	16.46	14.31

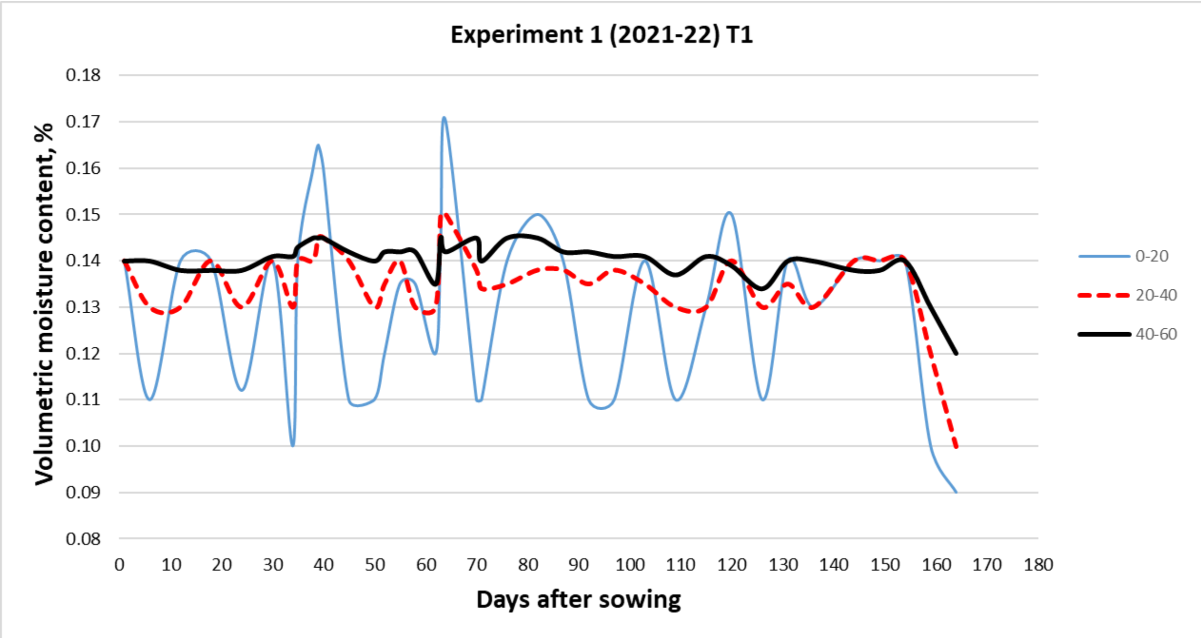

Fig. 2. Temporal variation of soil moisture in chilli crop root zone at 20% MAD (T1) of available soil moisture during experiment

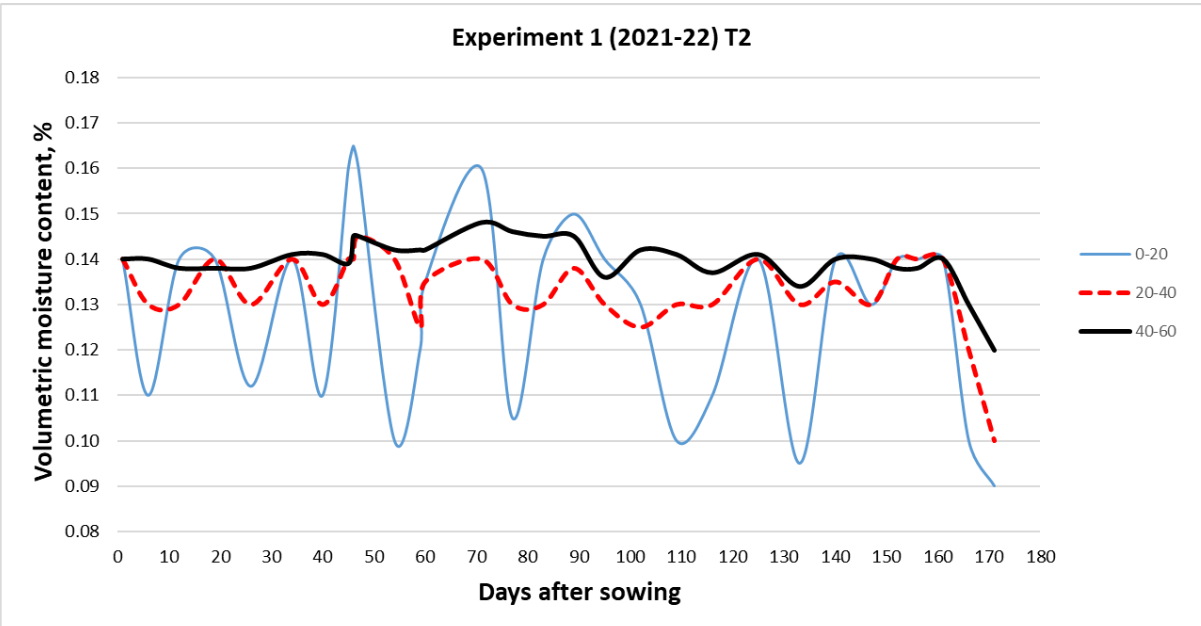

Fig. 3. Temporal variation of soil moisture in chilli crop root zone at 40% MAD (T2) of available soil moisture during experiment

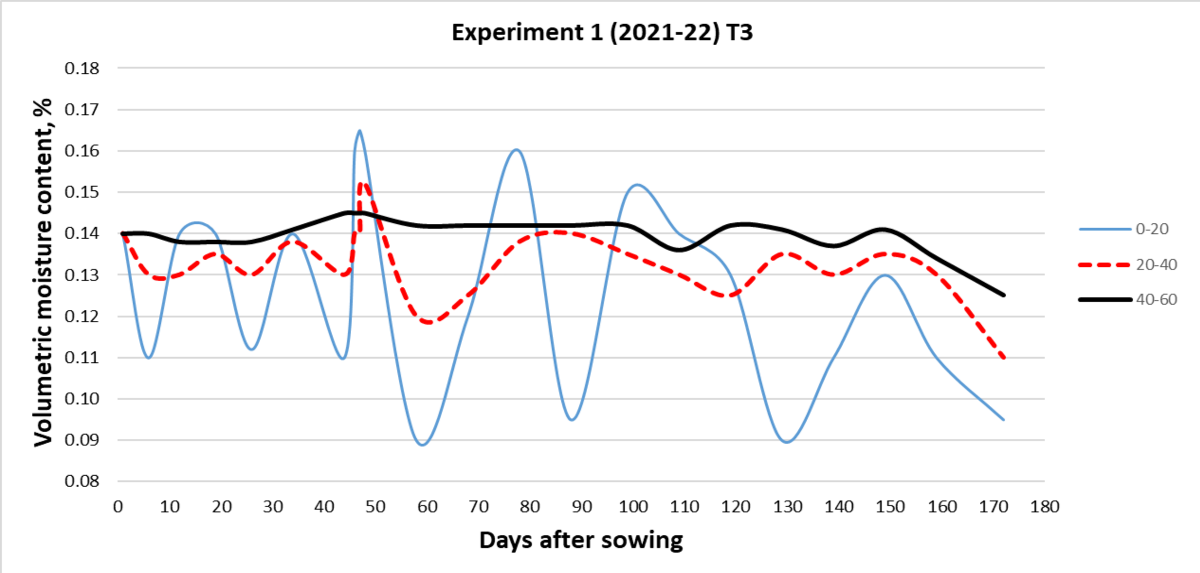

Fig. 4. Temporal variation of soil moisture in chilli crop root zone at 60 % MAD (T3) of available soil moisture during experiment

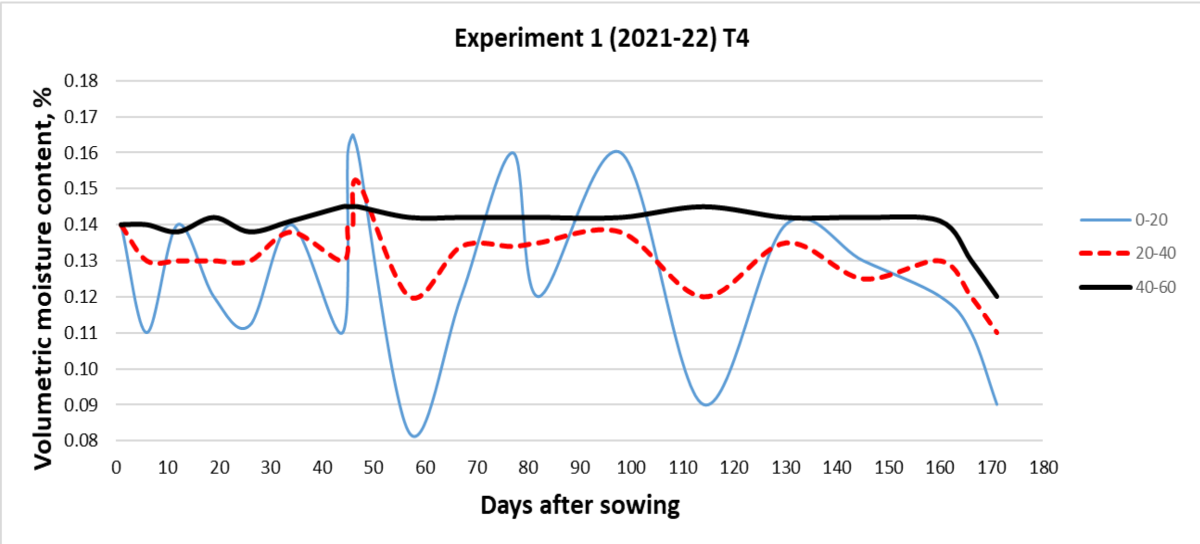

Fig. 5. Temporal variation of soil moisture in chilli crop root zone at 80% MAD (T4) of available soil moisture during experiment

IV. CONCLUSION

As a result of the study, it was found that under conditions, when people impose soil water stress at non-critical stages of growth, the plants tend to exhibit abnormal growing habits. The irrigation is to be scheduled at 40% maximum allowable depletion of available soil water for chilli crop grown in sandy loam soils in a sub-tropical humid region. A soil water stress of 40 % MAD gives the highest crop water use efficiency as well as field water use efficiency. The highest yield of 7624 kg/ha was obtained under least water stress condition (T_1) for chilli crop. It was also noticed that for scheduling of irrigation for chilli crop, the 0-20 cm soil profile should be considered as most of the water was found to be extracted from this layer by the plant.

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