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Soil profile water extraction based irrigation management of potato crop

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Abstract
Efficient management of depleting water resources is important in order to enhance crop productivity and to attain high water use efficiency. The study aimed at identifying irrigation management practices, which could result in water savings through deliberate under irrigation. Field experiments were conducted at experimental site of Central Research field of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj., India on potato crop (*Kufri badshah*) over a period of two years during the winter seasons of 2020-2021and 2021-2022. The crop was planted in first week of December and harvested in the last week of March spanning approximately 110 days. Three irrigation treatments were maintained based on the maximum allowable depletion (MAD) of available soil water. The treatments were 20% (T_1), 40% (T_2) and 60% (T_3) maximum allowable depletion of available soil water. No soil water stress was maintained at the initial stages of the crop development so as to allow the plants attain a healthy growth. Soil moisture content was measured by gravimetric method periodically in 0-15, 15-30 and 30-45 cm soil profiles. Soil moisture showed a cyclic temporal variation at all three selected soil depths. The magnitude of this variation was higher in 0-15 cm soil profile and decreased in 15-30 and 30-45 cm soil profiles in that order. This trend was observed at all schedules of irrigation. Field experiments revealed that irrigation schedule with 40% maximum allowable depletion of available soil water gave the maximum water use efficiency for potato crop. For scheduling of irrigation of potato crop, 0-30 cm soil profile should be considered as most of the required water to be extracted from this layer by the plant.

Keywords: Irrigation, soil water, water use efficiency, water scarcity, potato

Introduction
The potato (*Solanum tuberosum*) is an important vegetable belonging to the family Solanaceae. It is believed to have been introduced in India from Europe in the early seventeenth century. China, Russia, Ukraine and India are the leading potato growing countries of the world (Kashyap and Panda, 2002b) [13]. India stands at fifth position, both in terms of area and production of potato. The potato is rich in protein, fat, carbohydrates and minerals. In fact, it is considered to be a complete, nutritious staple food. The potato is grown in almost all states in India. Potato crop in Uttar Pradesh contributes about 32 per cent to the country's total output. Nearly 80 per cent of the crop is grown in the Indo-Gangetic plains comprising Punjab, Haryana, Uttar Pradesh, Bihar, Uttarakhand and West Bengal. Potatoes amount to about 1.23 percent of the gross agricultural produce in India. The potato is generally cultivated in winter but in a few areas it is also cultivated during the summer and rainy seasons. Of the country's total potato production, 81% occurs in the winter season, 13% in summer and 6% during the rainy season (Kashyap and Panda, 2002c) [14].
World food production is primarily dependent on irrigated lands. Currently there is about 250 million-hectare of irrigated land worldwide, most of which utilizes surface irrigation. Although irrigated land constitutes only 17% of the total agricultural land, it produces 36% of the world's total food requirement (Kashyap, 2013) [9]. India is bestowed with ample land potential but not corresponding water resources. The two, in fact, are not evenly matched in respect of space and/or time and the country as a whole therefore can be categorized as water constrained.
Accurate estimation of crop water demand is an important aspect of agricultural planning (Kashyap, 2006) [7]. The water requirement varies widely from crop to crop and also during the period of growth of individual crop (Panda *et al*., 2003a) [11]. In case of situations where water supply is limited, the irrigation demand of the entire cropping pattern cannot be met fully

(Panda *et al*., 2003b) [10]. In these conditions, deliberate under irrigation, also known as deficit irrigation can play a major role. By 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 harvestable yield (Kashyap, 2007) [8]. 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) [5]. Rising cost of irrigation water pumping, low commodity prices, inadequate irrigation system capacities and limited irrigation water supplies are among the reasons that many irrigators deliberately apply less water than that is required for maximum yield (Craciun and Craciun, 1999) [3]. The goal of deficit irrigation is to enhance economic returns by reducing water and/or energy use. Crops are exposed to varying levels of environmentally induced stresses during their growth cycles. In as much as stress affects crop productivity, the relationship and method of quantifying and monitoring crop stress have received intensive research attention (Wanjura *et al*., 1992; Osvald and Osvald, 1991; Nesmith and Ritchie, 1992; Craciun *et al*., 1993; Craciun and Craciun, 1994) [17, 16, 15, 4, 2].

With these background considerations, a comprehensive field investigation was undertaken on a coarse textured lateritic soil at the The field experiment was carried out at the experimental site of Central Research field of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, India. Crop cultivar Kufri badshah of potato, which is a popular variety of the region, was selected as the experimental crop. The effects of various scheduling of irrigation on the profile soil water status, crop yield and water use efficiency were studied. Irrigation schedules were based on 20, 40 and 60% maximum allowable depletion (MAD) of available soil water (ASW). The investigation on potato crop was completed in two crop seasons during 2020-2021 and 2021-2022. 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 potato crop.

Material and methods

The reported study was carried out at the experimental site of Central Research field of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj. India. Prayagraj district Uttar Pradesh, India is situated at 25.27° north and 81.50° east latitude with an altitude of 98 m above the mean sea level. The climate is typically semi-arid and sub-tropical. The maximum temperature reaches up to 47.9 °C in the summers and drops down to 1.5 °C in the winters. The average rainfall in this area is about 1100 mm per annum. Most of which generally occur during winter season. During both crop experiments, the temperatures were generally moderate and suitable for the growth of potato crop. The physical properties of the soil of experimental crop field used for potato crop are presented in Table 1.

Table 1: Physical properties 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	31.2	28.5	39.5	1.62	16.2
15-30	33.4	32.2	35.6	1.57	11.3
30-45	35.5	36.3	30.5	1.56	3.80
45-60	33.8	31.1	32.0	1.64	2.80

Field Capacity: 32% volumetric basis, and
Permanent Wilting Point: 12% volumetric basis

Field experiments were conducted on potato (*Solanum tuberosum* L.) crop cultivar Kufri badshah, which is a popular, 100-110 days vegetable crop of the locality and suits to the prevailing climate in the winter season (November to March) of the year. It thrives well in all soil textures that have good internal drainage. The optimum temperature for the crop growth is 15-18^{0}C (Doorenbos and Kassam, 1979) [5]. Water deficits during the period of stolonization, tuber initiation and tuber bulking have the greatest adverse effect on yield, whereas early vegetative and maturation periods are less sensitive (Doorenbos and Kassam, 1979) [5]. Both the experiments had scanty rainfall and hence provided the best opportunity to maintain the irrigation treatments.

Soil profile moisture measurement

A vertical section of the soil profile was cut to observe the different layers present in the soil. It was observed that three layers were present in the soil such as: 0-15 cm, 15-45 cm and beyond 45 cm. These soil layers were distinctly different from each other particularly due to the difference in soil texture and presence of organic matters. The soil moisture was measured gravimetrically in all soil profiles.

Field layout and experimental details

Potato was grown on experimental terraces, which were divided into 20 plots of 2 m x 2 m size. Farm Yard Manure (FYM) was mixed manually with top 15 cm soil layer at the rate of 30 kg/ha 10 days before sowing. Phosphorus (Single super phosphate) and Potassium (Muriate of potash) fertilizers were applied in the doses of 100 kg and 80 kg per hectare, respectively and mixed manually with top 15 cm of soil one week before sowing. Nitrogen (Urea) was applied in two equal doses of 60 kg/ha each. The first dose of Nitrogen was applied ten days before sowing and the second dose was applied approximately 30 days after sowing. Potato seeds were cut into pieces of approximately 25-30 cm^3 size consisting of at least one bud or sprout. The seed potatoes were sown at a row spacing of 50 cm and the plant spacing was kept at 22 cm during both crop experiments.

Irrigation treatments and scheduling

The irrigation treatments consisted of irrigation scheduling,
MAD = 20% of ASW (T_1),
MAD = 40% of ASW (T_2) and
MAD = 60% of ASW (T_3),
based on maximum allowable depletion (MAD) of available soil water (ASW) in the root zone criteria.

The available soil water was taken as the difference between root zone water storage at field capacity (32% V/V) and permanent wilting point (12% V/V). For estimating water storage, the effective root zone of potato crop was considered as 45 cm (Allen *et al*., 1998) [1], irrespective of growth stage. Using the data of soil moisture gravimetrically, the percentage depletion of available soil water in the effective root zone was estimated. The experimental plots were irrigated using furrow method of irrigation. Water was applied with the help of a hosepipe and a water meter in order to have 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. These data were necessary for the estimation of water use efficiencies and in evaluating the effects of different treatments on the crop yield. In order to assess the change in soil water balance, soil moisture was measured in 0-15, 15-30 and 30-45 cm soil profiles. The moisture content of soil layers was measured gravimetrically on every two day interval.

Results and Discussion

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 and 30-45 cm soil profiles during both experiments. No soil water stress was maintained during the critical stages of crop growth such as early vegetative growth, tuber initiation and tuber bulking. The irrigation treatments were applied with effect from 35 DAS during both 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 potato crop (Fig. 1 to 3) revealed that the soil moisture experienced a cyclic temporal variation at all depths. This trend was observed irrespective of the level of irrigation (MAD level). The amplitude of this cyclic variation was higher in upper layers than in lower layers.

A comparison of the both experiments in terms of the temporal variation of soil moisture in the experimental potato crop plots at 20% maximum allowable depletion (MAD) of available soil water (ASW) are presented in Fig. 1a and 1b. In experiment 1, there was a rapid decline of soil moisture (Fig. 1a) in 0-15 cm soil profile from 80 days after sowing (DAS) to the end of growth period. Since the irrigation was frequent under this irrigation schedule, therefore, the amplitude of cyclic variation and the time span of irrigation were low. The lower layers of 15-30 and 30-45 cm soil profiles also exhibited a gradual decline with effect from 80 DAS upto the end of the growth period. In experiment 2 also, the rate of depletion was faster with effect from 85 DAS (Fig. 1b) than the earlier periods at all soil depths. The crop was irrigated at an interval of 3-4 days under this irrigation schedule. The amplitude of cyclic variation was more in 0-15 cm soil profile because most of the applied irrigation water was lost through evaporation from the soil surface beside the transpiration. 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 and 30-45 cm soil profiles did not exhibit much cyclic variation. This trend was observed in both experiments.

The amplitude of cyclic variation decreased towards the lower soil profiles. Soil moisture in 0-15, 15-30 and 30-45 cm soil profiles under 40% MAD (T_2) also exhibited cyclic pattern (Fig. 2a and 2b). The results reveal that the extraction of the soil water was from all the layers of the root zone but most of the extraction was from 0-15 and 15-30 cm soil profiles. Since the irrigation was scheduled at 40% depletion, the plants extracted water to meet the evapotranspiration demand of the crop. The irrigation treatments were started 35 DAS during experiment 1. The magnitude of cyclic variation was higher in 15-30 and 30-45 cm soil profiles as compared to similar layers of T_1 during both crop seasons. The frequency of irrigation was lower under this irrigation schedule than that of T_1, therefore, the time span of cyclic variation was higher than that of T_1.

The variations of soil moisture with depth (Fig. 3a and 3b) under 60% MAD (T_3) revealed that high amplitude of cyclic variation was noted in all soil profiles of the root zone. Since the irrigation were scheduled at 60% MAD, the time span of variation was also higher in this irrigation schedule compared to T_1 and T_2. The plant roots penetrated deeper in search of water as it was not adequate in the upper soil layers. A decreasing trend was observed with effect from 50 DAS in all soil profile (Fig. 3a). This is because the roots of the plants were developed by this time and they extracted the water from these lower layers also in addition to 0-15 and 15-30 cm soil profile. During experiment 2 (Fig. 3b), the soil water was also contributed from 30-45 cm soil profiles with effect from 50 DAS because of developed root system.

Water use efficiency

The water use efficiency was estimated during both experiments to have an idea as to how effectively the irrigation water was used by the crop (Table 2). The water use efficiency was be described in two ways (a) crop water use efficiency and (b) field water use efficiency.

Crop water use efficiency

The crop water use efficiency was considered as the ratio of the fresh tuber yield and the crop evapotranspiration. The results pertaining to water use efficiency of the potato crop under different scheduling of irrigation during both crop experiments are presented in Table 2. As evident from the table that the highest crop water use efficiency was attained when irrigation was scheduled at 40% depletion of ASW (T2). A similar trend was observed during both crop seasons.

Field water use efficiency

The field water use efficiency was estimated in terms of fresh tuber 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 (T2). The trend was similar during both crop seasons. Field experiments conducted during both crop seasons revealed that irrigation schedule with 40% maximum allowable depletion of available soil water could safely be maintained during the non-critical stages to save water without sacrificing the tuber yield.

A similar study by Kashyap, 2005 [6] and Kashyap and Panda 2002a [12] over a period of four years gave somewhat similar results. However, in order to have more confidence on the results and to arrive at conclusions and recommendations, which would have greater authentication, the study should be extended for more irrigation treatments such as 45%, 50% and 55% as 60% depletion has already indicated lower values of water efficiencies. Studies may be conducted taking the following two aspects into consideration which may give more water saving.

Table 2: Water use efficiency (WUE) of potato crop under different scheduling of irrigation during experiments 1 (2020-21) and 2 (2021-22)

Experiment	Treatments	Fresh tuber yield (Kg/ha)	ET (mm)	Irrigation (mm)	Crop-WUE (Kg/ha/mm)	Field-WUE (Kg/ha/mm)
2020-2021	T1	11854	169	225	70.24	52.68
	T2	12410	165	218	75.21	56.92
	T3	10970	158	215	69.43	51.02
2021-2022	T1	13240	188	221	70.42	59.90
	T2	14150	182	211	77.74	67.06
	T3	12610	178	204	70.84	61.81

1. Refilling only a part of the root zone instead of refilling the entire root zone, and
2. Refilling partially (not upto field capacity, while irrigating)

The magnitude of water saving was found relatively higher when simulation studies were conducted by the authors using crop growth simulation models, where uniform soil water stress was maintained throughout the crop growth season. In the reported study conducted at Central Research field of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Fig. 4), a methodology has been recommended, on the basis of crop experiments, which emphasizes the importance of maintaining soil moisture stress during non-critical stages of crop growth to attain high water use efficiency under water scarcity conditions.

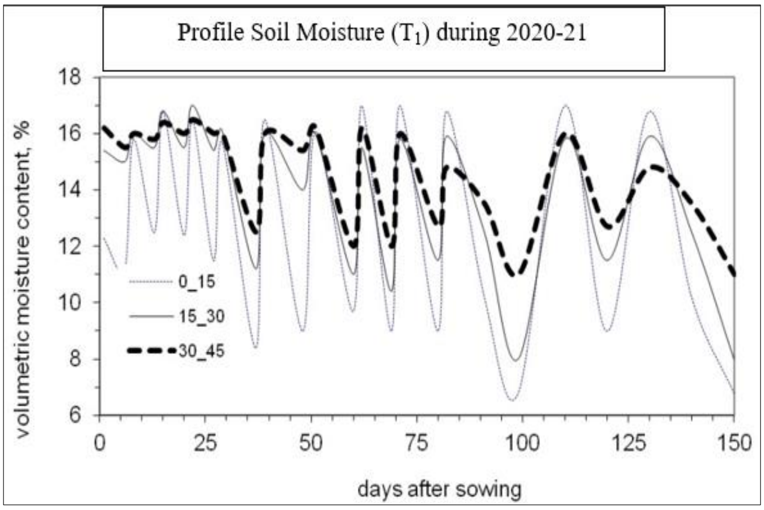

Fig 1 a): Profile soil moisture content for T1 (20% MAD) during 2020-21

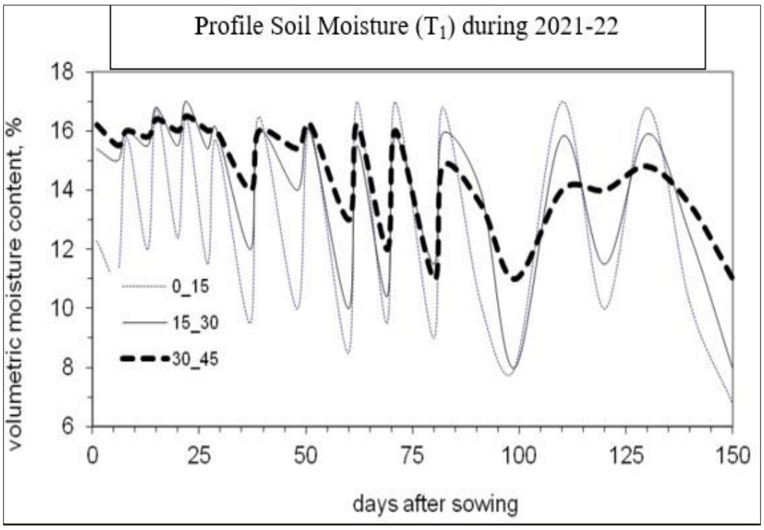

Fig 1 b): Profile soil moisture content for T1 (20% MAD) during 2021-22

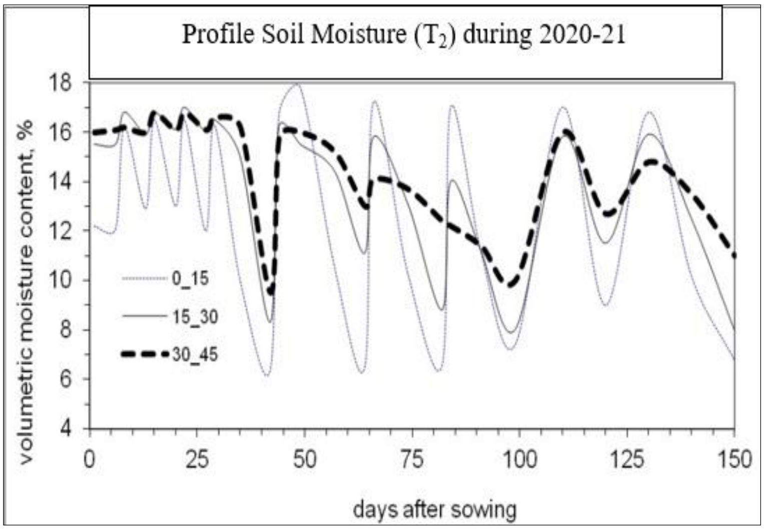

Fig 2 a): Profile soil moisture content for T2 (40% MAD) during 2020-21

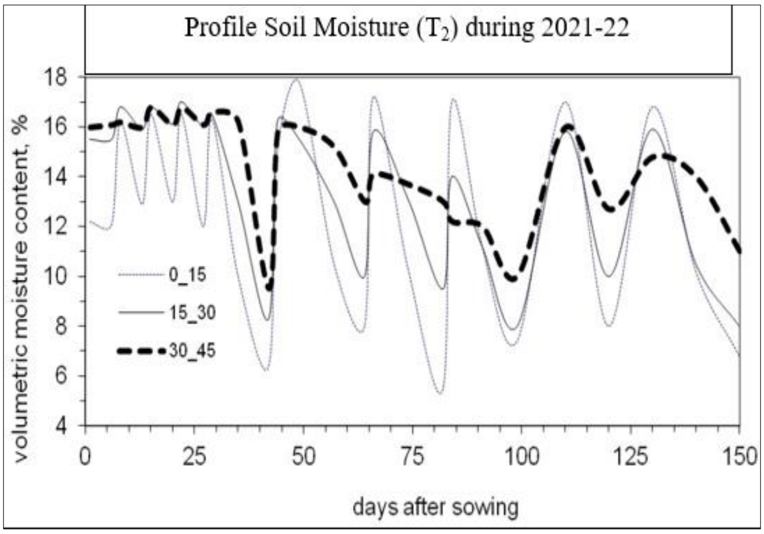

Fig 2 b): Profile soil moisture content for T2 (40% MAD) during 2021-22

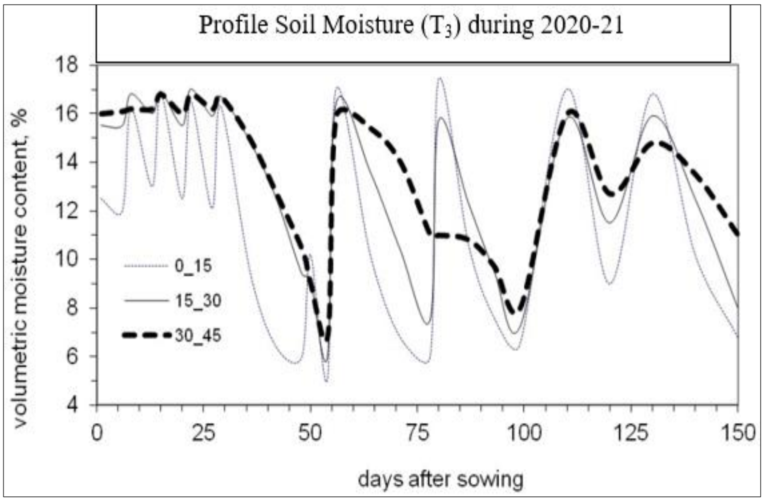

Fig 3 a): Profile soil moisture content for T3 (60% MAD) during 2020-21

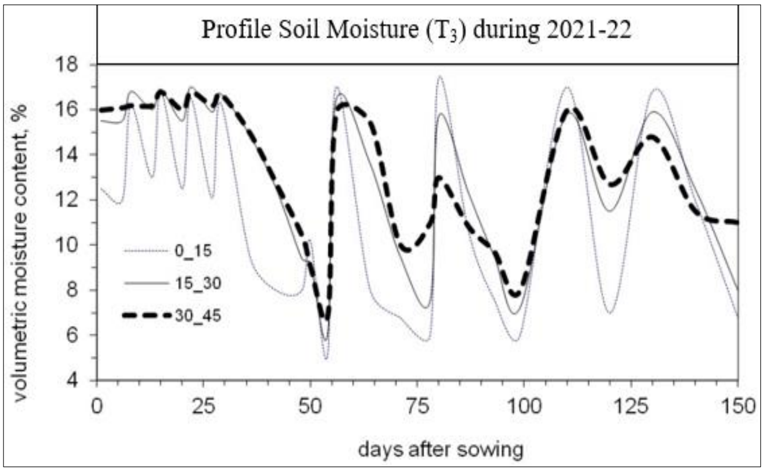

Fig 3 b): Profile soil moisture content for T3 (60% MAD) during 2021-22

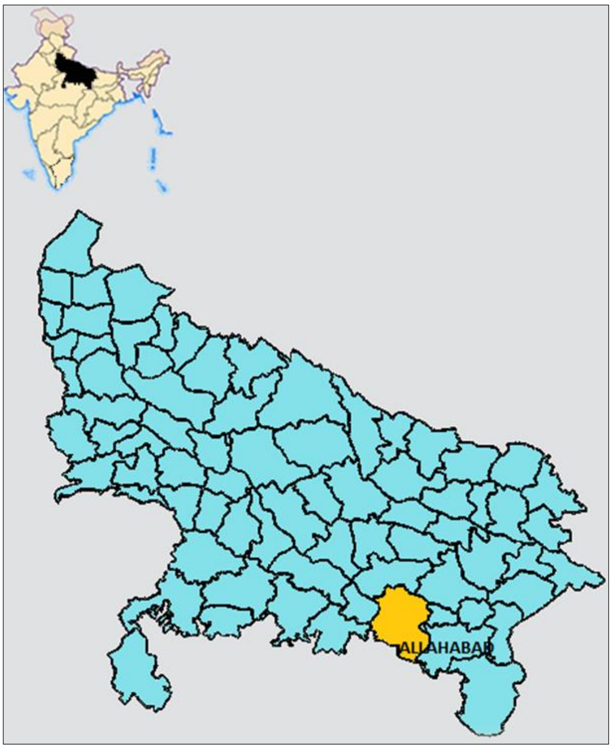

Fig 4: Location of the study area Prayagraj (formerly Allahabad), UP, India

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 40% maximum allowable depletion of available soil water for potato crop grown in sandy loam soils in a tropical region. A soil water stress of 40% MAD gives the highest crop water use efficiency as well as field water use efficiency. Only 0-30 cm of soil profile, instead of 0-45 cm, is to be considered for scheduling of irrigation for potato crop grown in a sandy loam soil, since most of the water used by the crop is extracted from this layer.

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