Effect of crop establishment methods and irrigation scheduling on growth and soil nutrient status of wheat

Abstract

This split-plot experiment conducted during the rabi seasons of 2020-21 and 2021-22 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, delved into the intricate relationships between crop establishment methods and irrigation scheduling on wheat crop height and soil nutrient content. Employing a split-plot design with three main plot treatments—Conventional, Zero tillage, and Raised bed method—and five sub-plot treatments based on irrigation scheduling using maximum allowable depletion (MAD) of available soil water, the study revealed that raised bed sowing significantly enhanced plant height, with the peak observed under the Crown Root Initiation (CRI) + 30% depletion of available soil moisture (DASM) treatment at all observation stages. Notably, despite these pronounced effects on plant growth, the chosen crop establishment methods and irrigation schedules did not result in any significant differences in the available nitrogen, phosphorus, and potassium (NPK) in the soil after the wheat harvest. This nuanced exploration of agricultural practices emphasizes the complexity of nutrient dynamics in soil-plant systems and underscores the necessity for further research to refine nutrient management strategies and promote sustainable wheat cultivation practices.

Key words:Crown Root Initiation, Maximum allowable depletion, Raised bed method, Zero tillage

1 Introduction

Wheat (*Triticumaestivum* L.) is one of the most important cereal crop for the majority of world's populations. It is cultivated globally due to its wider adaptability to different climatic and edaphic conditions. The rice–wheat (RW) cropping systems occupies 13.5 million hectares (m ha) in the Indo-Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan and are fundamental to employment, income and livelihood for millions of people in the region. In India alone, RW rotation occupies about 10.5 m ha and contributes about 40% of the country's total food grain basket [1]and these two crops meet about 80% of the carbohydrate food requirement of India. With the adoption of high yielding varieties and improved crop management practices, the productivity of RW system in the region was remarkably increased and had ushered into green revolution (GR) primarily in North-Western India.

It contributed 731.28 million metric tons to the global food grain basket in the year 2018-19, covering an area of about 215.4 million ha world-wide. While in India, this crop covered about 29.65 million ha during the recent past 2018-19 and accounted the production of about 102.2 million metric tons with average productivity of 3.42 t ha^{-1} [2].The requirement for wheat in India by 2020 has been projected to be between 105 to 109 mt as against 102.2

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Many researchers concluded that the two main reasons for low wheat productivity are poor crop establishment and improper scheduling of irrigation. The selection of suitable sowing method plays an important role in the placement of seed at proper depth, which ensures better emergence and subsequent crop growth. Wheat is planted with different sowing methods depending upon the available soil water, time of planting, amount of residue in the field and availability of planting machine[4]. Conventional crop establishment method involves intensive tillage which leads to gradual decrease in soil organic matter due to accelerated oxidation and crop residue burning causing pollution, greenhouse gases emission, loss of the plant nutrients and biodiversity of soil. The origin of raised bed cultivation has traditionally been associated with water management issues either by providing opportunities to reduce the impact of excess water in rainfed conditions or to more efficiently deliver irrigation water in high production irrigated systems[5]. Wheat planting on raised beds could improve mechanical weed control, water and fertilizer use efficiencies. Bed and furrow method of planting provide ease in water and fertilizer application.Zero tillage has been widely acclaimed as highly effective practice for conservation of soil and water as compared with conventional tillage.Another method of crop establishment is, dry seeding of wheat followed by irrigation is a new practice for wheat cultivation is area where irrigation water is limited. The seed should be placed 4-5 cm deep in a row and then irrigate the field. This would result in maximum germination, better crop set and ultimately leading to higher yield and water productivity [6].

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The importance of crop establishment methods and irrigation scheduling in determining the availability of nutrients in soil is paramount for optimizing agricultural productivity. Crop establishment methods such as Conventional, Zero tillage, and Raised bed sowing play a crucial role in shaping soil structure and influencing nutrient distribution. For instance, Zero tillage practices, which minimize soil disturbance, have been associated with improved soil organic matter and microbial activity, potentially enhancing nutrient availability [7]. Raised bed sowing, on the other hand, alters the physical arrangement of soil, affecting water retention and nutrient distribution, with potential implications for nutrient availability [8]. Understanding how these establishment methods influence nutrient dynamics is essential for farmers seeking sustainable practices that maximize soil fertility and nutrient utilization.

Irrigation scheduling further amplifies the complexity of nutrient availability in the soil. The timing and amount of water supplied through various irrigation strategies can significantly impact soil moisture levels, subsequently influencing nutrient solubility and plant uptake. For example, maintaining soil moisture at the Crown Root Initiation (CRI) stage and throughout subsequent stages can potentially optimize nutrient absorption by the crop [9]. Conversely, excessive irrigation leading to over-depletion of soil moisture may impact nutrient mobility and result in leaching, affecting nutrient retention in the root zone [10]. The intricate interplay between crop establishment methods and irrigation scheduling is a critical determinant of nutrient availability in soil, underscoring the need for a comprehensive understanding to guide sustainable agricultural practices.

Water shortage is becoming the most important limiting factor for wheat production. Under such situation, the deficit irrigation becomes more important in recent years as there is continuous decrease in available fresh water that can be used by agricultural production.

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Thus, it become relevant to identifying growth stages of a particular cultivar under local conditions of climate and soil fertility allows irrigation scheduling to maximize crop yield and to enable the most efficient use of scarce water resources [11].

Irrigation scheduling is very critical for obtaining optimal crop yields. For optimum irrigation scheduling, sound knowledge of the soil water status, crop water requirements, crop water stress status and potential yield reduction under water stressed conditions is prerequisite to maximize profits and optimize the use of water and energy. There are different methods of irrigation scheduling *viz*., critical crop growth stage approach, soil moisture depletion approach (whether in terms of soil water content or soil water potential), atmospheric evaporativity approach, irrigation water at different cumulative pan evaporation approach, etc. can be adopted for optimizing the timing of irrigation.

Keeping the above facts in view present investigationwasplaned with following objectives:1. To study the effect of crop establishment method and irrigation scheduling on growth of wheat. 2. To evaluate the soil fertility under different crop establishment method and irrigation scheduling.

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2 Materials and Methods

2.1 Experimental site

The agricultural Research Farm is situated at about 10-kilometer distance from Varanasi railway station in South-West direction. The geographical location of the farm lies in the North-East plain zone of eastern Uttar Pradesh which is situated at 25°18' N latitudes, 83°03' E longitude and at an altitude of 75.7 meters above the mean sea level. The field was homogeneously fertile well drained with even topography and uniform textural makeup as well as an assured source of water supply.

2.2 Climate and weather

Varanasi has subtropical climate characterized by extremely hot summer and cold winter. May and June are the two hottest months with the mean maximum temperature range from 39° to 43°C. January is the coldest month with mean temperatures varying from 9 °C to 10 °C. The temperature starts to rise from the middle of February and reaches its maximum in the month of May and the middle of June. The third week of June is the normal period of onset of monsoon which lasts up to the end of September or sometime in the first week of October. The average rainfall received in this area is about 1100 mm and average evapotranspiration with an annual moisture deficit of 400 mm and moisture deficit index of 20 to 40 %. The rainfall received in percentage basis, 84% is received during June to September, 07% from October to December, 6% during January to February and 9.3% from March to May as pre-monsoon rains. The mean relative humidity is 88 percent which rises from July to September up to 91 % and in the month of April to early June falls down to 39 percent.

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2.3 Experimental design and layout

The experiment was conducted using a split plot design, which involved three main plot treatments and five sub plot treatments, each replicated three times. The main plot treatments were crop establishment method i.e. S1-Conventional S2-Zero tillage S3-Raised bed method while, sub plot treatments were irrigation scheduling based on maximum allowable depletion (MAD) of available soil water (ASW) viz. (I1) CRI only (I2) CRI+60%MAD of ASW, (I3) CRI+50 % MAD of ASW (I4) CRI+40%MAD of ASW and (I5). The confined crop residue was cleared from the zero tillage plot in both years of the study. At the time of establishing the main plot treatment, the initial organic carbon content was 0.41%. The available nitrogen, phosphorus, and potassium were 207.59, 24.10, and 218.90 kg ha-1, respectively. The experiment was conducted throughout the academic years 2020-21 and 2021-22. The experiment consisted of a total of fifteen treatment combinations, which were derived from three main plots and five sub-plots. Additionally, there were a total of 45 plots, which served as the experimental units. This entire arrangement was implemented in the second year to verify the results. The randomization principles were followed to allocate the treatments among the experimental units. The analysis considers the effects of block borders, field borders, plot borders, and irrigation channels.

2.4 Crop raising technology

A rectangular plot of land with a consistent fertility and even topography was selected, and it was laid out in an undisturbed manner using the primary plot treatments (crop establishment procedures). In the Kharif season, the field for conventional till paddled transplanted rice (CTPTR) treatment was ploughed twice in dry conditions and then ploughed under water (puddling). In the zero tillage (ZT) treatments, Glyphosate was applied at a rate of 1 kg a.i. ha-1 seven days before seeding to control weeds. During the Rabi season, the convention till wheat (CTW) plots and raised bed plot were ploughed twice using a cultivator, and the seeds were sown using a seed drill. However, sowing in raised beds was performed using a bed planter. The zero till wheat (ZTW) treatment involved using a ZT seed drill for sowing without any prior tillage. A dosage of Glyphosate at a rate of 1 kilogrammeof active ingredient per hectare was applied in all ZTW treatments prior to sowing. The recommended dose of 150 kg N, 60 kg P_2O_5, 60 kg K_2O and 5 kg Zn ha-1 was applied for wheat thorough area, DAP and MOP.The seed rate utilised was 100 kg per hectare. The sowing took place on December 23rd in the 2020-21 season and on December 22nd in the 2021-22 season. The sowing process involved the use of a tractor-drawn zero till fertilizer-seed drill. In the raised bed plot, the seeds were sown using a raised bed planter. The depth control wheel ensured that the seeding depth was consistently maintained at a range of 3-4 cm. The herbicide Sulfosulfuron + Metsulfuron (Total) was given at a rate of 40 grammes per hectare of active ingredient. The application was done using a knapsack sprayer equipped with a flat fan nozzle, using 400 litres of water. The herbicide was applied 30 days after sowing. In addition, a herbicide surfactant was employed to reduce herbicide waste and enhance its effectiveness.

Irrigation was carried out using water extracted from a tube well. Table 3.8 provides the specific information regarding the irrigation methods used for each treatment. The irrigation schedule followed the prescribed treatments. The initial irrigation was applied to all treatments during the CRI stage. Subsequently, the irrigation was applied according to the treatment, specifically using the maximum allowable depletion (MAD) of available soil water (ASW) from field capacity. A buffer channel with a width of 0.25 metreswas constructed between the plots to avoid the leakage and excessive flow of water from the main and sub irrigation channels. Robust embankments were constructed along all sides of the plot. A water metre was employed to quantify the volume of irrigation water. The irrigation treatments were implemented in accordance with the predetermined layout.

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Irrigation scheduling was done on the basis of percentage depletion of available soil water (ASW) in the effective root zone. The maximum allowable depletion (MAD) of ASW of 30, 40, 50 and 60% was applied in the I2, I3, I4 and I5 treatments, respectively. Whereas, the I1 treatment received single irrigation at crown root initiation of the wheat. In order to assess the changes in soil water status in the crop root zone, soil moisture was determined by gravimetric method in 0-30, 30-60, 60-90 and 90-120 cm layers of soil profile. The percentage depletion of available soil water in the effective root zone was estimated by using the following equation:

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$$Depletion(\%) = 100 \times \frac{1}{n}\sum_{n=1}^{n}\left(\frac{Fci - \Theta i}{Fci - PWP}\right)$$

Where,*n*the number of sub-divisions of the effective root zone depth used in the soil moisture sampling, FC*i*the soil moisture at field capacity for *i*th layer, θ*i*the soil moisture in *i*th layer and PWP the soil moisture at permanent wilting point.

The amount of water applied after the attainment of pre-defined MAD (%) was calculated as

$$VD = MAD\frac{(Fci - \Theta i)Rz \times A}{100}$$

Where, *V*d the amount of irrigation water applied, R*Z* the effective root zone depth and *A* the plot surface area. The first post-sowing irrigation of 70 mm was given 3 weeks after sowing (*i.e.* CRI stage, 21-24 DAS) to all treatments. From the 3rd WAS, the 30, 40,50 and 65% MAD of ASW was maintained in I2, I3, I4 and I5 treatment, respectively. Under I1 treatment, the irrigations were applied at CRI stage only.

2.5 Observation and analysis

Five plants at random had been selected and marked from each treatment plot so that the plant height could be measured. Wheat plant height was measured with a metre scale from the base of the plant to the tip of the plant before spike emergence and from the base of the plant to the tip of the spike after heading. The average height was then estimated and given in centimetres.

Available nitrogen in the soil was analyzed by alkaline permanganate method of Subhiah and Asija[12] with Kjeldahl distillation unit. The sodium bicarbonate (NaHCO3) method, which was proposed by Olsen et al. [13], was employed to calculate the amount of available phosphorus in the soil. This technique involves extracting 2 g of processed soil with 40 ml of 0.5 N NaHCO3 solution (pH adjusted to 8.5) using a mechanical agitator for a duration of 30 minutes. Following the filtration of the suspension, a blue hue was observed, which was subsequently quantified at 760 nm using a spectrophotometer to determine the phosphate concentration in the soil (available P kg ha^{-1}).In order to ascertain the amount of potassium present in the soil, a suspension of conventional NH_4AOC and soil was prepared and buffered to a pH of 7.0. The flame photometer method[14] was utilised to determine the potassium concentration in the solution; the results were expressed as available K in kg ha^{-1}.

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2.6 Statistical analysis

The data collected from multiple observations during the investigation period were organised and statistically analysed to determine the significance of differences between the treatments. The analysis was conducted using the appropriate method of Analysis of Variance, F and t tests, for a split plot design. The level of significance was set at p=0.05. Whenever the F test yielded a significant result, the critical difference (CD) was calculated. The results have been assessed and discussed based on the data from two years of experimental (2020-21 and 2021-22).

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3. Results and discussion

3.1 Plant height

The observation pertaining to the effect of crop establishment method and irrigation regime on plant height of wheat crop recorded at 30, 60 and 90 DAS of crop presented in Table 1. The plant height gradually increases during both the year of observation.The critical examination of data found that the significantly maximum height of plant among the crop establishment was observed in raised bed sowing at 60 DAS which was at par with conventional method of sowing during both the year of experimentation. At 30 DAS and 90 DAS crop establishment method did had significant effect on plant height during both the year of observation.

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Data given in Table 1 further reveals that application of irrigation at different moisture regime showed significant effect on height of plant except at 30 DAS during both the year of experimentation. The maximum plants height was observing in CRI + 30 % MAD of ASW at all stage of observation, however at 60 DAS it was at par with CRI + 40% MAD of ASW. At 90 DAS it was at par with CRI + 40% MAD and CRI +50 % MAD of ASW during both the year of investigation. The interaction effect of different crop establishment method and irrigation scheduling on plant height of wheat crop found to be non-significant in both the year.

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Crop development is results of environmental, genetic, and agronomic factors. Since, all the crop establishment methods followed in similar environmental condition, the variation observed in plant height of crop could be due to their ability to utilize soil and environmental factor to which plant crop plant expose during their life cycle [15, 16]. Plants grow vegetatively primarily through the formation of somatic cells, which lead to the growth and development of new leaves, stems, and roots[17]. These meristematic tissues have a very active protein metabolism, and the photosynthetic sites that these cells transport are primarily used for protein and nucleic acid synthesis[18].

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Plant height is mostly determined by the plants genetic composition [19], these are cell differentiation, plant hormones, mineral use efficiency, depth of root and environmental factors that vary depending on the method of sowing. The maximum plant at 60 DAS of sowing recorded with raised bed method of sowing which was significantly higher than zero tillage but at par with conventional method of sowing. The minimum plan height recorded with zero tillage method of sowing. These findings are similar with the findings of [20, 21]who had found significant difference in plant height of wheat affected by different crop establishment method.

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Table 1.Effect of crop establishment method and irrigation scheduling on plant height of wheat.

Treatment	30 DAS		60 DAS		90 DAS	
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Crop establishment						
Conventional	24.22	24.80	52.86	52.69	85.95	86.55
Zero tillage	23.74	23.99	50.91	51.31	84.09	84.09
Raised bed (2 row per bed)	25.30	25.51	54.92	55.34	88.44	88.57
Sem ±	0.441	0.351	0.748	0.709	0.942	1.028
CD (p=0.05)	NS	NS	2.94	2.78	NS	NS
Irrigation scheduling						
CRI	24.66	25.30	46.55	46.96	80.13	80.13
CRI + 60 % MAD of ASW	24.17	24.58	51.98	52.02	84.73	85.29
CRI + 50 % MAD of ASW	24.33	24.65	53.86	54.06	87.20	87.42
CRI + 40 % MAD of ASW	24.35	24.67	55.51	55.79	88.74	88.74
CRI + 30 % MAD of ASW	24.59	24.64	56.58	56.74	89.98	90.43
Sem ±	0.484	0.396	0.859	0.794	1.005	1.176
CD (p=0.05)	NS	NS	2.51	2.32	2.93	3.43
Interaction	NS	NS	NS	NS	NS	NS

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3.2 Available NPK in soil after harvest

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3.2.1 Available nitrogen (kg/ha)

Data on available nitrogen as affected by crop establishment method and irrigation scheduling are presented in Table 2. It was clear from the data that crop establishment method recorded non-significant difference on available nitrogen in soil after harvest. However, the maximum available nitrogen in soil after harvest recorded in raised bed method of sowing and minimum in conventional method of sowing during both the year. The data indicated that the irrigation scheduling also recorded non-significant difference on available nitrogen in soil after harvest. Whereas, the maximum available nitrogen in soil recorded in application of irrigation water at CRI stage only and the minimum being in CRI+30%MAD of ASW during both the year.The interaction effect of crop establishment method and irrigation scheduling on available nitrogen in soil after harvest found to be non-significant in both the year of observation.

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This finding contradicts some previous research, which suggested that tillage practices could influence soil nitrogen dynamics. Traditionally, zero tillage has been associated with improved nitrogen retention due to reduced soil disturbance, potentially resulting in higher organic matter decomposition and mineralization of nitrogen compounds [22].Raised bed sowing, on the other hand, is often presumed to enhance water and nutrient-use efficiency [23]. The lack of disparity in available nitrogen levels challenges these established notions.

One possible explanation for this unexpected result could be the complexity of nitrogen cycling in soil. Other factors such as microbial activity, soil structure, and organic matter content may have overshadowed the impacts of crop establishment methods and irrigation scheduling on available nitrogen. Additionally, the chosen crop, in this case, wheat, may have unique interactions with the soil nitrogen pool that merit further investigation [24].

Furthermore, the absence of a significant difference in available nitrogen levels challenges the conventional wisdom regarding the influence of irrigation scheduling. Previous studies have suggested that optimal irrigation practices could impact nutrient availability by affecting soil moisture levels [25]. However, the current study did not find substantial evidence to support such a relationship.

Table 2.Effect of crop establishment method and irrigation scheduling on available nitrogen after harvest of crop

Treatment	Available N (kg/ha)	
	2020-21	2021-22
Crop establishment		
Conventional	199.6	200.8
Zero tillage	201.2	202.1
Raised bed (2 row per bed)	204.2	205.8
Sem ±	4.94	4.96
CD (p=0.05)	NS	NS
Irrigation scheduling		
CRI	206.8	208.1
CRI + 60 % MAD of ASW	204.0	205.2
CRI + 50 % MAD of ASW	202.0	203.0
CRI + 40 % MAD of ASW	198.7	200.2
CRI + 30 % MAD of ASW	196.9	198.1
Sem ±	5.10	5.12
CD (p=0.05)	NS	NS
Interaction	NS	NS

3.2.2 Available phosphorus (kg/ha)

Data on available phosphorus as affected by crop establishment method and irrigation scheduling are presented in Table 3.

It is clear from the data that crop establishment method did not show significant differences on available phosphorus in soil. However, the maximum phosphorus in soil after harvest recorded with raised bed method of sowing during both the year.Data indicated that irrigation scheduling did not show significant difference on available phosphorus in soil after harvest. The maximum available phosphorus in soil after harvest in recorded with CRI+ 30 % MAD of ASW but the difference was non-significant. The lowest available phosphorus uptake in soil after harvest recorded with application of irrigation water at CRI stage only during both the year of observation.

This finding deviates from conventional wisdom, as previous research has often emphasized the impact of tillage practices on soil phosphorus dynamics. Zero tillage, for instance, has been associated with enhanced phosphorus availability due to reduced soil disturbance and the preservation of organic matter [26]. Raised bed sowing, with its potential benefits for water and nutrient management, was also anticipated to influence phosphorus levels in the soil [27]. However, the current study did not reveal any discernible effects.

The absence of significant differences in available phosphorus could be attributed to various factors. Phosphorus is known for its complex interactions with soil particles, and its mobility is influenced by factors such as soil pH, organic matter content, and microbial activity [29]. Additionally, the chosen crop, wheat, may exhibit specific phosphorus utilization patterns that are not strongly influenced by the tested establishment methods and irrigation schedules [29].

Moreover, the results challenge prevailing notions about the impact of irrigation scheduling on soil phosphorus availability. While optimal irrigation practices are often thought to influence nutrient dynamics, particularly phosphorus [30], the current study did not identify any significant variations associated with different irrigation scheduling approaches.

Table 3.Effect of crop establishment method and irrigation scheduling on available phosphorus after harvest of crop

Treatment	Available P (kg/ha)	
	2020-21	**2021-22**
Crop establishment		
Conventional	18.2	18.51
Zero tillage	19.13	19.28
Raised bed (2 row per bed)	20.03	20.25
Sem ±	0.47	0.475
CD (p=0.05)	NS	NS
Irrigation scheduling		
CRI	18.27	18.53
CRI + 60 % MAD of ASW	18.78	19
CRI + 50 % MAD of ASW	18.99	19.29
CRI + 40 % MAD of ASW	19.4	19.74
CRI + 30 % MAD of ASW	20.15	20.18
Sem ±	0.49	0.498
CD (p=0.05)	NS	NS
Interaction	NS	NS

3.2.3 Available potassium (kg/ha)

The summary of availability of potassium in soil after harvest as affected by different treatment given in Table 4 Data clearly indicated that available potassium in soil after harvest did not had significant due to crop establishment. The maximum available potassium in soil after harvest recorded with raised bed method of sowing but the difference was non-significant.Critical examination of data showed that irrigation scheduling had non-significant difference in available potassium in soil. However, the maximum available potassium in soil after harvest recorded with application of irrigation water at CRI stage only and minimum being in treatment CRI+30% MAD of ASW.The interaction effect of crop establishment method and irrigation scheduling on available potassium in soil after harvest found to be non-significant in both the year of observation.

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The absence of significant differences in available potassium could be attributed to the inherent characteristics of potassium in soil dynamics. Potassium is known for its relatively low mobility in the soil compared to other nutrients, such as nitrogen [26].The lack of significant variation across the different crop establishment methods and irrigation schedules suggests that these factors may not exert a substantial influence on potassium availability post-harvest.

Furthermore, potassium is often strongly adsorbed by soil particles, and its release into the soil solution is influenced by factors like soil pH and cation exchange capacity [29]. The chosen crop, wheat, may have exhibited consistent potassium uptake patterns regardless of the tested agronomic practices.

In the context of irrigation scheduling, the study did not reveal any significant impact on available potassium. Unlike some other nutrients, potassium does not move readily with water in the soil profile, and its availability may be less sensitive to variations in soil moisture levels [23].

In conclusion, the non-significant differences in available potassium in the soil after the harvest of wheat suggest that potassium dynamics are likely influenced by factors beyond the scope of the tested crop establishment methods and irrigation scheduling. The study underscores the importance of recognizing the distinct behavior of individual nutrients in the soil-plant system, with potassium exhibiting a degree of stability that is less responsive to certain agronomic practices.

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Table 4.Effect of crop establishment method and irrigation scheduling on available potassium after harvest of crop

Treatment	Available K (kg/ha)	
	2020-21	2021-22
Crop establishment		
Conventional	216.6	215.9
Zero tillage	218.9	217.7
Raised bed (2 row per bed)	218.3	217.8
Sem ±	5.3	5.28
CD (p=0.05)	NS	NS
Irrigation scheduling		
CRI	220.3	219
CRI + 60 % MAD of ASW	219.4	218.1
CRI + 50 % MAD of ASW	218.1	217.2
CRI + 40 % MAD of ASW	216.2	216.2
CRI + 30 % MAD of ASW	215.7	215.1
Sem ±	5.53	5.51
CD (p=0.05)	NS	NS
Interaction	NS	NS

Conclusion

In this comprehensive exploration of crop establishment methods and irrigation scheduling on wheat growth, our findings reveal that raised bed sowing and CRI + 30% DASM consistently led to significantly greater plant height, emphasizing their potential for optimizing crop development. However, the absence of significant differences in available nitrogen, phosphorus, and potassium (NPK) in the soil after the wheat harvest suggests that the selected establishment methods and irrigation schedules did not exert a pronounced impact on soil nutrient levels. This underscores the intricate dynamics of nutrient cycling and the need for a more nuanced understanding of agronomic practices to influence soil fertility. Moving forward, we recommend further investigations to elucidate the intricate interactions between crop management strategies and nutrient availability, ensuring the development of targeted and sustainable agricultural practices for optimal wheat crop productivity.

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