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Impact of Conservation Tillage and Nitrogen Management on Soil Temperature and Soil Moisture in Aerobic Rice

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the impact of different tillage practices, namely Conventional Tillage (CT) (T1), Minimum Tillage with residue retention (MT) (T2) and Zero Tillage (ZT) (T3) and nitrogen fertilizer schedules 100% RDN (N1) (120 kg ha^{-1}), 100% RDN + foliar spray of nano urea 2.5 ml l^{-1} at active tillering and panicle initiation stage (N2), 100% RDN + foliar spray of nano DAP 2.5 ml l^{-1} at active tillering and panicle initiation stage (N3), 75% RDN + Nano urea 2.5 ml l^{-1} at active tillering and panicle initiation stage (N4), 75 % RDN + Nano DAP 2.5 ml l^{-1} at active tillering and panicle initiation stage (N5) on soil temperature, moisture and their interaction in aerobic rice cultivation.

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Soil temperature was measured using digital thermometer and soil moisture was determined by Owen drying method. Results revealed that soil temperature and soil moisture was significantly influenced by tillage practices and Nitrogen fertilizer schedules showed no significant effect on soil temperature and soil moisture. Zero tillage (T3) consistently recording the lowest soil temperatures compared to T1 and T2 in both years. During *rabi* 2022-2023, T3 recorded 18.23°C in the 1st week, significantly lower than T1 (19.32°C). This trend persisted in the *rabi* 2023-2024, with T3 recording 27.1°C in the 19th week, significantly lower than T1 (28.61°C). In terms of soil moisture, zero tillage (T3) also consistently resulted in the highest moisture levels. During *rabi* 2022-2023 season, T3 recorded 18.93% soil moisture in the 1st week, significantly higher than T1 (18.11%). This pattern continued in the *rabi* 2023-2024, with T3 maintaining significantly higher moisture levels in most weeks. Zero tillage is effective in reducing soil temperature and enhancing soil moisture retention. Minimum tillage with residue retention performing similar to zero tillage.

Keywords: Aerobic rice; soil moisture; soil temperature; tillage practices.

1. INTRODUCTION

In aerobic rice cultivation, managing soil moisture and temperature is essential for optimizing crop growth and productivity. Unlike traditional flooded rice systems, aerobic rice relies on soil water rather than standing water, making the management of soil conditions critical for maintaining an adequate supply of moisture [1]. This system reduces water usage, but the soil's ability to retain moisture and regulate temperature becomes a key determinant of crop success, especially under changing environmental conditions. Tillage practices play a significant role in shaping the soil environment, influencing both moisture retention and temperature dynamics. Conventional tillage, which involves extensive soil disturbance through ploughing, can enhance water infiltration by loosening the soil structure [2]. However, this process may lead to increased moisture loss through evaporation and higher soil temperatures due to the exposure of bare soil to direct sunlight [3]. Over time, this can negatively affect the soil's ability to support aerobic rice under water-limited conditions. On the other hand, conservation tillage, such as minimum and zero tillage, focuses on reducing soil disturbance. These practices aim to preserve the natural soil structure, often by retaining crop residues on the surface. This layer of residues acts as a protective cover, reducing evaporation, maintaining soil moisture for longer periods [4], and insulating the soil, thus moderating temperature fluctuations [5]. Conservation tillage can also improve soil organic matter, enhance water infiltration rates, and promote better root development, all of which are vital for sustaining moisture levels and creating a favorable microclimate for aerobic rice cultivation. Nitrogen management, another key factor in aerobic rice cultivation, can also affect soil moisture and temperature. Proper nitrogen application promotes healthy plant growth, influencing canopy development and root architecture, which in turn affects the soil's microclimate. Selecting appropriate nitrogen rates and sources is essential for maintaining soil conditions favorable for aerobic rice, especially under limited water availability. Effective management of both tillage and nitrogen is crucial for sustaining soil health and ensuring optimal conditions for aerobic rice cultivation. Their combined effects on soil moisture and temperature play a pivotal role in determining the success of rice production in water-limited environments.

2. MATERIALS AND METHODS

Field experiment was conducted for two successive *rabi* seasons of 2022-23 and 2023-24 on sandy clay loam soil at Indian institute of rice research, Hyderabad, Telangana. The experimental site was slightly alkaline in reaction, low in available nitrogen, medium in available phosphorus and potassium. The experiment consisted of three tillage treatments *viz.,* Conventional tillage (T1), Minimum tillage with residue retention (T2) and Zero tillage (T3) as first factor and five nitrogen fertilizer schedules *viz.,* 100% RDN (N1), 100% RDN + Foliar spray of 2.5 ml l^{-1} nano urea at active tillering stage and panicle initiation (N2), 100% RDN + Foliar spray of 2.5 ml l^{-1} nano DAP at tillering and before panicle initiation stage (N3), 75% RDN + Foliar spray of 2.5 ml l^{-1} nano urea at tillering and before panicle initiation stage (N4) and 75% RDN + Foliar spray of 2.5 ml l^{-1} nano DAP at tillering and before panicle initiation stage (N5) as second factor. The experiment was laid out in strip plot design with three replications.

The meteorological data (Fig. 1) during *rabi* seasons of 2022-23 and 2023-24 recorded variations in temperature, relative humidity, rainfall, sunshine hours, evaporation and wind velocity across the two seasons. During *rabi* 2022-23, the maximum temperature ranged from 26.7ºC to 36.5ºC, while the minimum temperature varied between 11.2ºC and 22.3ºC. Similarly, in *rabi* 2023-24, the maximum temperature ranged from 27.7ºC to 39.7ºC, and the minimum temperature fluctuated between 15.3ºC and 23.5ºC. Moderate temperatures were observed in the early rice growth stages of both seasons, while higher temperatures were recorded towards the season end.

Mean relative humidity varied from 46.0% to 71.8% during *rabi* 2022-23 and from 47.4% to 73.7% in *rabi* 2023-24. Higher humidity levels were recorded during the early stages of both seasons, with a gradual decrease toward the later stages. Rainfall was minimal during both seasons. In *rabi* 2022-23, rainfall ranged from 0.00 mm to 9.26 mm. In *rabi* 2023-24, rainfall ranged between 0.00 mm and 1.4 mm. The overall precipitation was low, with most weeks receiving no rainfall. Sunshine hours in *rabi* 2022-23 varied between 3.6 to 9.9 hours per day, while in *rabi* 2023-24, the range was from 4.2 to 9.3 hours per day. Higher sunshine durations were recorded in the mid to late stages of both seasons, with relatively shorter hours at the beginning. Evaporation rates followed a similar pattern in both years. In *rabi* 2022-23, evaporation ranged from 0.0 mm to 6.4 mm, while in *rabi* 2023-24, it varied from 3.0 mm to 8.3 mm. Higher evaporation rates were observed in the later stages of both seasons, coinciding with increasing temperatures and longer sunshine hours. Wind velocity remained moderate during both growing periods. In *rabi* 2022-23, wind speed ranged from 1.4 km hr^{-1} to 4.0 km hr^{-1}, while in *rabi* 2023-24, it varied between 2.9 km hr^{-1} and 5.0 km hr^{-1}.

Soil temperature was measured in the experimental field daily at 9 am and 2 pm at 10 cm depth by using the Digital Soil Thermometers with a stainless-steel stem and an LCD display designed for meteorological applications. Which were working similar to bent stem earth thermometers. Instrument was kept for set of time. Instrument features a measuring range from -50°C to +300°C (-58°F to +572°F) with the option to select temperature units in Celsius or Fahrenheit. The accuracy of the measurements ranges from 0.01°F to +80°F, with an accuracy tolerance of ±1°F or ±2°F depending on the specific temperature range. Daily soil temperatures were calculated by averaging the soil temperatures at 9 am and 2 pm. The daily temperatures were grouped into weekly. Weekly averages were calculated to reduce the day-to-day soil temperature fluctuations.

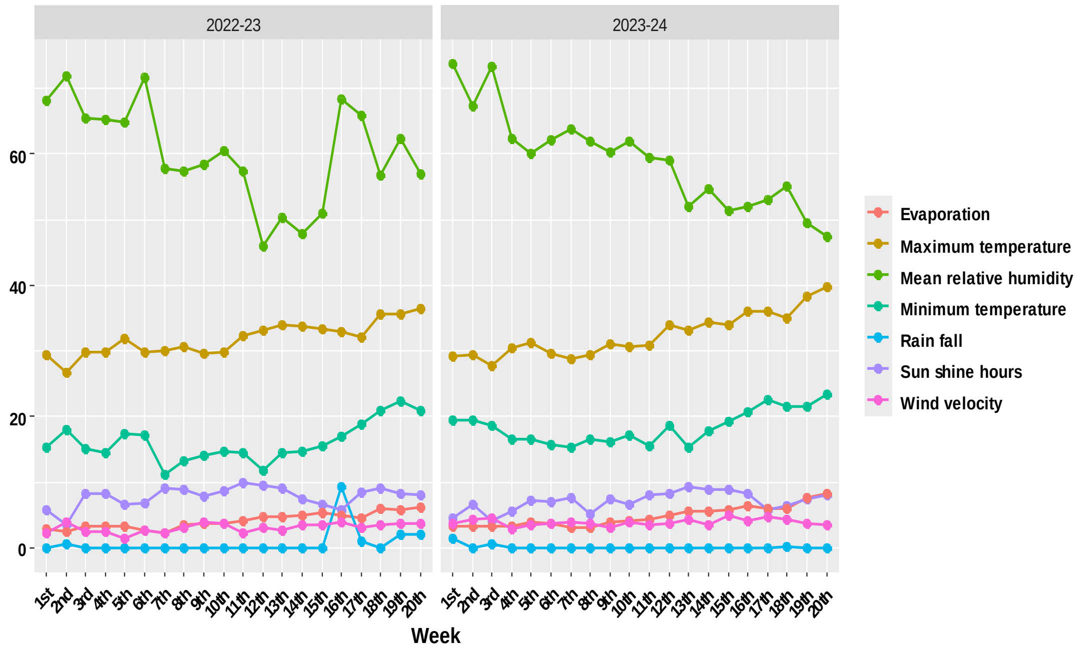

Fig. 1. Weather data during rabi season of 2022-23 and 2023-24

The soil moisture content expressed by weight as the ratio of the mass of water present to the dry to the dry weight of the soil sample or by volume as ratio of volume of water to the total volume of the soil sample. Moisture content of soil by drying the soil to constant weight and measuring the soil sample mass after and before drying. The water mass is the difference between the weights of the wet and oven dry samples. The criterion for a dry soil sample is the soil sample that has been dried to constant weight in oven at temperature 105^{o}C.

Repeated measures analysis of variance (ANOVA) was done for soil temperature and moisture in each one-week period and each of the two years using R studio, with time as a within-subject factor and tillage practices and nitrogen management type as between-subjects among treatment means (multiple comparisons) were determined using Duncan's multiple range test (DMRT) and were considered significant at P = 0.05.

3. RESULTS AND DISCUSSION

Soil temperature: Data pertaining to soil temperature by tillage practices and nitrogen fertilizer schedules was presented in Tables 1 and 2 respectively. The results of the repeated measures ANOVA indicated that significant differences were observed solely due to tillage practices for each week and the average weekly data. However, there were no significant differences related to nitrogen fertilizer schedules and the interaction between tillage practices and nitrogen fertilizer schedules for each week and the mean weekly soil temperature. During *rabi* 2022-2023, zero tillage (T3) consistently resulted in significantly lower soil temperatures across most weeks. In the 1st week, T3 recorded a soil temperature of 18.23°C, significantly lower than conventional tillage (T1) at 19.32°C. This trend continued through the season, with T3 showing the lowest soil temperatures in key weeks like the 4th week (19.99°C) and 10th week (20.27°C). During 2nd week (T3: 21.56°C; T2: 21.91°C) and the 3rd week (T3: 20.31°C; T2: 20.65°C), T3 temperatures remained lower but did not differ significantly from T2. Meanwhile, conventional tillage (T1) maintained the highest soil temperatures throughout the season, particularly in the mid and late stages, with values like 21.67°C in the 5th week and 25.67°C in the 20th week. In the 6th week, T1 recorded 21.31°C, not significantly different from T2 (T2: 20.45°C) but still higher than T3 (T3: 20.11°C). In the 12th week, T1 (21.71°C) showed significant differences from T2 (21.01°C) and T3 (20.67°C). During *rabi* 2023-2024 season, the pattern remained consistent, with T3 again displaying significantly lower soil temperatures in several weeks. In the 19th week, T3 recorded a soil temperature of 27.1°C, compared to 28.61°C under conventional tillage (T1). In the 20th week, T3 maintained significantly lower soil temperatures at 28.58°C, with a difference of 1.5°C compared to T1 (30.01°C). Notably, in non-significant weeks like the 17th week (T3: 25.23°C; T1: 26.32°C), the differences were not significant, indicating T3 performance was similar to T1 but still lower.

In the pooled analysis (Fig. 1) of the 1st week, T3 recorded 18.88°C, significantly lower than T1 at 19.91°C. Similarly, in the 20th week, T3 had a pooled soil temperature of 26.32°C, which was significantly lower than T1 at 27.84°C. Across multiple weeks, such as the 10th (T3: 20.27°C, T1: 22.03°C), 12th (T3: 22.14°C, T1: 23.07°C), and 19th (T3: 25.09°C, T1: 26.68°C), zero tillage (T3) exhibited significantly lower soil temperatures compared to both conventional tillage (T1) and minimum tillage with residue retention (T2), reinforcing the consistent trend observed throughout the study. In both years significantly higher mean weekly soil moisture was observed under zero tillage (T3), which statistically comparable with minimum tillage with residue retention (T2) and significantly higher over conventional tillage (T1).

The observed phenomenon of reduced soil temperatures under zero tillage and minimum tillage with residue retention can be attributed to several factors. Primarily, these tillage practices minimize soil disturbance, which helps to preserve the natural soil structure and reduces the heat absorption capacity of the soil. This is further enhanced by the presence of crop residues, which provide insulation and shade, thus mitigating temperature fluctuations. Similar results reported by Dutta et al. [6]; Liu et al. [7]; Cerda et al. [8] and Hernanz et al. [9].

Soil moisture: Data pertaining to soil moisture by tillage practices and nitrogen fertilizer schedules was presented in Tables 3 and 4 respectively. The results of the repeated measures ANOVA indicated that significant differences were observed solely due to tillage practices for each week and the average weekly data. However, there were no significant

Table 1. Effect of tillage practices on soil temperature (ºC) during *rabi* aerobic rice

Week	2022-2023			2023-24			Pooled		
	T1	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**
1st	19.32a	18.55ab	18.23b	20.50a	19.60b	19.53b	19.91a	19.08b	18.88b
2nd	22.51a	21.91ab	21.56b	23.78a	23.16a	23.05a	23.14a	22.53a	22.31a
3rd	21.20a	20.65a	20.31a	22.43a	21.85a	21.76a	21.82a	21.25b	21.03b
4th	21.13a	20.32b	19.99b	22.33a	21.48a	21.39a	21.73a	20.90a	20.69a
5th	21.67a	20.72a	20.39a	22.73a	21.73b	21.64b	22.20a	21.23b	21.01b
6th	21.31a	20.45a	20.11a	22.65a	21.73a	21.64a	21.98a	21.09a	20.88a
7th	21.22a	20.81a	20.47a	22.35a	21.92a	21.83a	21.79a	21.37a	21.15a
8th	21.49a	20.99a	20.65a	22.71a	22.18ab	22.09b	22.10a	21.59b	21.37b
9th	20.76a	20.01a	19.68a	21.94a	21.14a	21.06a	21.35a	20.57b	20.37b
10th	21.37a	20.61b	20.27b	22.70a	21.90a	21.81a	22.03a	21.25b	21.04b
11th	21.40a	20.53b	20.20b	22.69a	21.77a	21.68a	22.05a	21.15b	20.94b
12th	21.71a	21.01ab	20.67b	24.44a	23.70b	23.61b	23.07a	22.36b	22.14b
13th	22.43a	21.51a	21.17a	23.71a	22.73a	22.63a	23.07a	22.12a	21.90a
14th	22.51a	21.59b	21.24b	24.55a	23.57a	23.47a	23.53a	22.58ab	22.36b
15th	22.58a	21.65b	21.31b	25.82a	24.84a	24.74a	24.20a	23.24b	23.02b
16th	22.87a	21.93a	21.58a	26.91a	25.91a	25.81a	24.89a	23.92a	23.70a
17th	22.78a	21.84b	21.50b	26.32a	25.33b	25.23b	24.55a	23.59b	23.36b
18th	23.93a	22.70a	22.34a	27.07a	25.78b	25.67b	25.50a	24.24ab	24.00b
19th	24.76a	23.44ab	23.08b	28.61a	27.22b	27.10b	26.68a	25.33b	25.09b
20th	25.67a	24.43ab	24.06b	30.01a	28.71b	28.58b	27.84a	26.57b	26.32b

Table 2. Effect of nitrogen fertilizer schedules on soil temperature (ºC) during *rabi* aerobic rice

Week	2023					2024					Pooled				
	N1	**N2**	**N3**	**N4**	**N5**	**N1**	**N2**	**N3**	**N4**	**N5**	**N1**	**N2**	**N3**	**N4**	**N5**
1st	18.86	18.82	19.14	18.58	18.54	19.93	19.88	20.23	19.69	19.69	19.40	19.35	19.69	19.14	19.11
2nd	21.70	22.23	22.59	21.97	21.92	22.93	23.49	23.88	23.22	23.16	22.31	22.86	23.23	22.59	22.54
3rd	20.46	20.95	21.29	20.70	20.65	21.65	22.16	22.53	21.90	21.85	21.05	21.56	21.91	21.30	21.25
4th	20.57	20.62	20.96	20.37	20.32	21.74	21.79	22.15	21.52	21.47	21.16	21.20	21.56	20.95	20.90
5th	21.18	21.02	21.37	20.77	20.72	22.21	22.05	22.42	21.78	21.73	21.69	21.54	21.90	21.28	21.23
6th	20.79	20.74	21.09	20.49	20.44	22.10	22.04	22.41	21.78	21.73	21.44	21.39	21.75	21.14	21.09
7th	20.37	21.11	21.46	20.86	20.81	21.45	22.24	22.61	21.97	21.92	20.91	21.68	22.04	21.42	21.37
8th	20.69	21.30	21.65	21.04	20.99	21.86	22.51	22.88	22.24	22.19	21.27	21.90	22.26	21.64	21.59
9th	20.20	20.29	20.64	20.05	20.00	21.35	21.45	21.81	21.19	21.14	20.77	20.87	21.22	20.62	20.57
10th	20.77	20.91	21.26	20.66	20.61	22.06	22.21	22.58	21.95	21.90	21.41	21.56	21.92	21.30	21.25
11th	20.88	20.83	21.18	20.58	20.53	22.13	22.08	22.45	21.82	21.77	21.51	21.46	21.81	21.20	21.15
12th	21.03	21.32	21.67	21.06	21.01	23.72	24.02	24.39	23.75	23.70	22.38	22.67	23.03	22.41	22.36
13th	21.87	21.82	22.18	21.56	21.51	23.11	23.06	23.44	22.79	22.74	22.49	22.44	22.81	22.18	22.13
14th	21.95	21.90	22.26	21.64	21.59	23.95	23.90	24.28	23.63	23.58	22.95	22.90	23.27	22.63	22.58
15th	22.02	21.97	22.33	21.71	21.66	25.22	25.17	25.55	24.89	24.84	23.62	23.57	23.94	23.30	23.25
16th	22.30	22.25	22.61	21.99	21.94	26.30	26.25	26.63	25.97	25.92	24.30	24.25	24.62	23.98	23.93
17th	22.21	22.16	22.52	21.90	21.85	25.72	25.67	26.05	25.39	25.34	23.96	23.91	24.28	23.64	23.59
18th	23.49	23.03	23.40	22.76	22.71	26.61	26.13	26.52	25.84	25.79	25.05	24.58	24.96	24.30	24.25
19th	24.32	23.79	24.17	23.51	23.46	28.14	27.59	27.98	27.29	27.24	26.23	25.69	26.07	25.40	25.35
20th	25.11	24.79	25.18	24.50	24.45	29.42	29.09	29.50	28.79	28.73	27.27	26.94	27.34	26.64	26.59

Table 3. Effect of tillage practices on soil moisture (%) during *rabi* aerobic rice

	202-23			2023-24			Pooled		
Week	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**	**T1**	**T2**	**T3**
1st	18.11a	18.18a	18.93a	17.24b	17.95ab	18.57a	17.68b	18.06ab	18.75a
2nd	17.45a	17.53a	18.28a	17.40a	17.68a	18.43a	17.42b	17.6ab	18.35a
3rd	17.26a	17.34a	18.11a	17.31a	17.64a	18.52a	16.72b	16.97b	17.87a
4th	16.14a	16.30a	17.22a	15.65a	15.86a	16.52a	15.97b	16.09b	16.70a
5th	16.29a	16.32a	16.89a	15.42b	15.99ab	16.52a	15.99b	16.33ab	16.89a
6th	16.55a	16.66a	17.26a	15.66b	16.44ab	16.62a	15.96b	16.51a	16.80a
7th	16.27b	16.58ab	16.98a	15.54b	16.32a	16.32a	15.98b	16.73a	16.63a
8th	16.42a	17.14a	16.94a	15.42c	16.26b	16.91a	15.84b	16.84a	17.04a
9th	16.26a	17.42a	17.16a	15.45b	16.16ab	16.38a	15.70c	16.08b	16.53a
10th	15.94b	16.00b	16.68a	15.68b	15.86b	16.72a	16.05b	16.17ab	16.95a
11th	16.42a	16.49a	17.19a	15.82b	16.03ab	16.61a	16.09b	16.23ab	16.87a
12th	16.36a	16.42a	17.12a	16.11a	16.43a	17.09a	16.42a	16.62a	17.31a
13th	16.74a	16.81a	17.52a	15.80b	16.22ab	16.99a	16.47b	16.72b	17.47a
14th	17.13b	17.21b	17.94a	16.05b	16.6ab	17.32a	16.62b	16.93b	17.66a
15th	17.19a	17.27a	18.01a	16.60c	17.15b	17.70a	16.92b	17.24b	17.88a
16th	17.25a	17.32a	18.06a	16.18b	16.68ab	17.65a	16.82b	17.11b	17.98a
17th	17.47b	17.54b	18.30a	16.66a	16.91a	17.64a	17.03a	17.19a	17.93a
18th	17.40a	17.47a	18.23a	17.19b	17.65ab	18.65a	17.63b	17.90b	18.79a
19th	18.07b	18.16b	18.94a	17.39b	17.82ab	18.58a	17.44b	17.70b	18.46a
20th	17.50b	17.58b	18.35a	17.25a	17.73a	18.34a	17.25b	17.54b	18.22a

Table 4. Effect of nitrogen fertilizer schedules on soil moisture (%) during *rabi* aerobic rice

Week	2023					2024					Pooled				
	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5	N1	N2	N3	N4	N5
1st	18.17	18.21	18.76	18.44	18.49	17.29	18.06	18.31	18.24	17.75	17.73	18.13	18.53	18.34	18.12
2nd	17.54	17.57	18.07	17.79	17.82	18.19	17.28	17.89	17.71	18.13	17.86	17.43	17.98	17.75	17.98
3rd	16.08	17.03	16.32	16.97	16.40	17.54	17.81	17.85	17.86	18.07	16.81	17.42	17.09	17.41	17.24
4th	16.10	16.40	16.85	16.57	16.62	15.41	16.36	16.41	15.78	16.13	15.76	16.38	16.63	16.17	16.37
5th	16.66	16.47	17.15	17.05	16.83	15.58	15.70	16.03	16.41	16.18	16.12	16.09	16.59	16.73	16.50
6th	16.20	16.41	16.99	16.80	16.67	15.90	15.90	16.44	16.50	16.48	16.05	16.16	16.71	16.65	16.58
7th	16.81	16.89	17.50	16.16	16.83	15.43	16.23	16.12	16.22	16.32	16.12	16.56	16.81	16.19	16.57
8th	16.70	16.01	18.12	16.16	17.75	15.81	15.90	16.63	16.27	16.39	16.26	15.95	17.37	16.22	17.07
9th	16.00	16.04	16.51	16.24	16.27	15.82	15.82	16.15	16.41	15.82	15.91	15.93	16.33	16.32	16.05
10th	16.49	16.53	17.00	16.73	16.76	16.14	15.64	16.12	16.81	15.73	16.32	16.08	16.56	16.77	16.25
11th	16.43	16.46	16.94	16.66	16.70	16.14	15.85	16.10	16.44	16.26	16.28	16.16	16.52	16.55	16.48
12th	16.81	16.85	17.33	17.05	17.09	16.25	16.27	16.82	16.83	16.56	16.53	16.56	17.08	16.94	16.83
13th	17.21	17.25	17.74	17.46	17.50	16.30	16.30	16.26	16.37	16.50	16.75	16.77	17.00	16.92	17.00
14th	17.27	17.31	17.81	17.52	17.56	16.51	16.61	16.81	16.56	16.82	16.89	16.96	17.31	17.04	17.19
15th	17.33	17.37	17.86	17.58	17.61	16.96	16.81	17.38	17.35	17.27	17.14	17.09	17.62	17.46	17.44
16th	17.55	17.59	18.09	17.80	17.84	16.75	16.70	17.01	16.84	16.92	17.15	17.14	17.55	17.32	17.38
17th	17.48	17.52	18.02	17.73	17.77	16.86	17.18	17.03	17.09	17.21	17.17	17.35	17.53	17.41	17.49
18th	18.17	18.21	18.72	18.42	18.46	17.68	17.57	17.96	17.87	18.09	17.92	17.89	18.34	18.15	18.28
19th	17.60	17.63	18.12	17.84	17.88	17.89	17.91	18.20	17.74	17.93	17.74	17.77	18.16	17.79	17.90
20th	17.36	17.40	17.88	17.60	17.64	17.45	17.65	17.77	18.16	17.87	17.41	17.52	17.82	17.88	17.75

differences related to nitrogen fertilizer schedules and the interaction between tillage practices and nitrogen fertilizer schedules for each week and the mean weekly soil moisture.

During *rabi* 2022-2023, zero tillage (T3) consistently recorded the significantly highest soil moisture compared to conventional tillage (T1) and minimum tillage with residue retention (T2). In the 1st week, T3 had a soil moisture of 18.93%, significantly higher than T1 (18.11%) and T2 (18.18%). In the 3rd week, T3 maintained the highest moisture level at 18.11%, but this difference was not statistically significant compared to T1 and T2. The trend continued into the 5th week, where T3 recorded 16.89%, again showing significant differences from T1 (16.29%) and T2 (16.32%). In later weeks, such as the 19th week (T3: 18.94%, significant) and the 20th week (T3: 18.35%, significant), T3 consistently had higher moisture levels compared to lower values in T1 and T2.

During *rabi* 2023-2024 season, zero tillage (T3) again showed significantly higher soil moisture in most weeks. In the 1st week, T3 recorded 18.57%, significantly higher than T1 (17.24%) and T2 (17.95%). The differences were more pronounced in later weeks, particularly in the 18th week (T3: 18.65%, significant) and the 19th week (T3: 18.58%, significant).

The pooled data (Fig. 2) confirms this trend, with zero tillage (T3) consistently resulting in the significantly highest soil moisture across the majority of weeks. In the 1st week, T3 recorded 18.75%, significantly higher than T1 (17.68%) and T2 (18.06%). The same pattern was observed in the 10th week (T3: 16.95%, significant) and 19th week (T3: 18.46%, significant), where T3 maintained significantly higher moisture levels compared to T1 and T2. Non-significant weeks included the 2nd week, 3rd week, 4th week, 6th week, 8th week, 9th week, 12th week, and 17th week, where all treatments had comparable moisture levels without significant differences. The comparative analysis also reveals that while the overall soil moisture levels were lower in the second season (2023-2024) than in the first (2022-2023), the relative differences between the tillage methods remained consistent. This may be attributed to various factors, including climatic conditions and soil health over the years. In both years significantly higher mean weekly soil moisture was observed under zero tillage (T3), which statistically comparable with minimum tillage with residue retention (T2) and significantly higher over conventional tillage (T1).

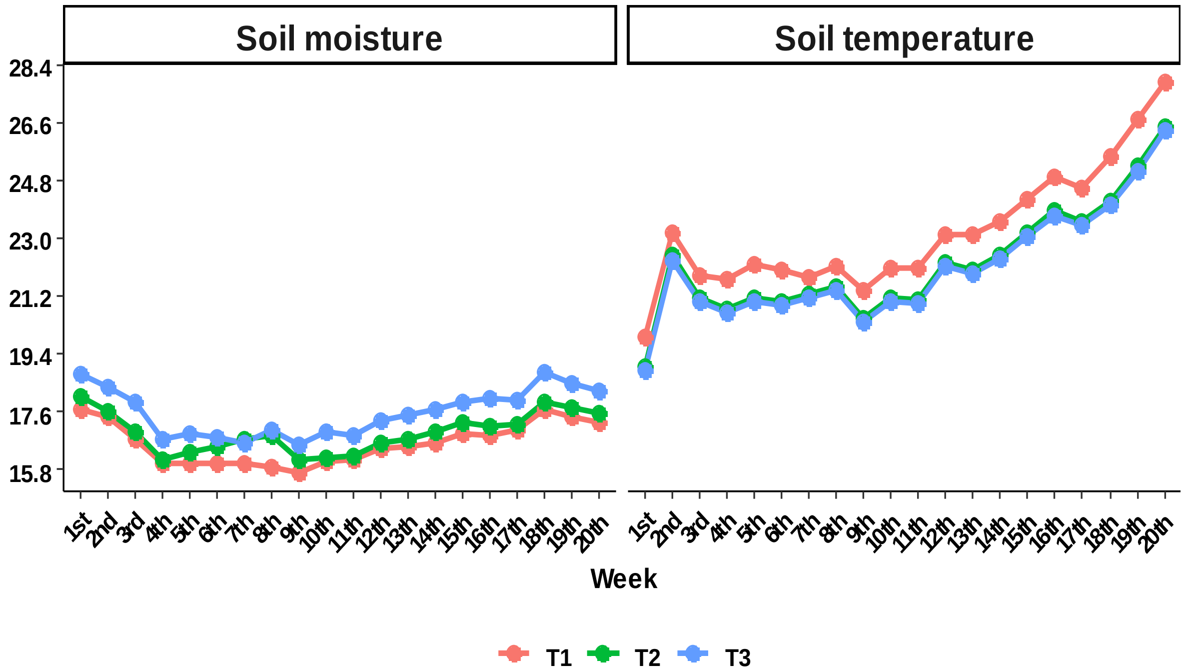

Fig. 2. Effect of tillage on soil temperature (°C) and soil moisture (%) during rabi 2022-23 and 2023-24 (pooled mean)

This trend can be attributed to the minimal soil disturbance in zero tillage, which helps reduce water evaporation and enhances moisture retention. The undisturbed soil structure in zero tillage maintains higher organic matter and improves infiltration, leading to better moisture conservation. In contrast, conventional tillage (T1), which involves intensive soil disturbance, likely promotes greater evaporation and reduces soil moisture retention. This is especially evident in the early and mid-season, where T1 recorded the lowest moisture levels. The frequent exposure of soil to air and sun in conventional tillage accelerates moisture loss, which may explain the lower soil moisture levels. Minimum tillage (T2) falls between these two extremes, showing intermediate moisture levels due to partial soil disturbance. While it conserves more moisture than conventional tillage, it statistically comparable with zero tillage in most of the weeks. The consistent higher moisture levels under zero tillage can be linked to improved soil structure, reduced evaporation, and better water infiltration, all of which contribute to enhanced moisture availability for crops during the *rabi* season. Similar results reported by Korba et al*.* [10]; Hu et al*.* [11]; Ayman [12]; Naveen et al. [13].

4. CONCLUSION

The study on the effect of tillage and nitrogen management on soil temperature and moisture in aerobic rice revealed that zero tillage consistently resulted in significantly higher soil moisture levels compared to conventional and minimum tillage. It was due to the minimal soil disturbance in zero tillage, which reduces evaporation and enhances moisture retention. Conventional tillage, with its intensive soil disturbance, showed the lowest moisture levels due to increased evaporation, while minimum tillage with residue retention demonstrated intermediate moisture levels but was statistically comparable to zero tillage in most weeks. Importantly, nitrogen fertilizer schedules showed no significant interaction on soil moisture and temperature. These findings highlight the importance of adopting reduced tillage practices like zero tillage to improve soil moisture conservation in aerobic rice cultivation.

5. RECOMMENDATIONS AND FUTURE SCOPE

The study recommends adopting zero tillage for aerobic rice cultivation due to its consistent ability to retain higher soil moisture compared to conventional and minimum tillage. This is especially beneficial in moisture-stressed environments, as zero tillage minimizes soil disturbance and reduces evaporation. While minimum tillage with residue retention showed results statistically comparable to zero tillage in most weeks, integrating residue retention with reduced tillage practices may further enhance soil health and moisture conservation. Nitrogen fertilizer schedules, which had no significant effect on soil moisture and temperature, should be optimized based on crop needs rather than soil conditions. Future research should focus on the long-term impact of zero and minimum tillage, combined with residue management, on soil health and crop yields, as well as further explore nitrogen management strategies that maximize crop efficiency without affecting soil moisture or temperature.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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