E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(11): 355-359
Received: 25-09-2025
Accepted: 26-10-2025

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Harnessing conservation and nutrient management practices to enhance water use efficiency and soil moisture estimation in finger millet (*Eleusine coracana* L.) under the central plain zone of Uttar Pradesh

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i11e.4186

Abstract
A Field experiment was also carried out at kharif seasons of 2023 and 2024 at Soil Conservation and Water Management Farm of Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, to determine the impact of conservation management and nutrient management on soil moisture estimation and water use efficiency (WUE) in finger millet (Eleusine coracana L.). The experiment was Conducted in a factorial randomized block design (FRBD) with three conservation practices C_1: Conventional tillage, C_2: Zero tillage, and C_3: Raised bed—and six nutrient management treatments from the recommended dose of fertilizers (RDF) to nano-fertilizer combinations. Findings indicated that the conservation and nutrient management practices significantly influenced soil moisture and WUE in both the years as well as combined over both the years. Among the conservation tillage practices, C_2 always maintained the maximum soil moisture (335.83 mm) and WUE (17.60 kg ha^{-1} mm^{-1}) than conventional tillage. Among the nutrient treatment, F_5 (100% NPK + Nano urea + Nano DAP) had the maximum soil moisture (331.66 mm), and F_6 (50% RDF + Nano urea + Nano DAP) had the maximum WUE (16.51 kg ha^{-1} mm^{-1}). The improved efficacy of these treatments is because of improved soil aggregation, better water holding capacity, and improved nutrient-use efficiency owing to the application of nano-fertilizers. Generally, the combination of zero tillage with nano-based nutrient management was the most efficient for maximizing finger millet soil water balance and water productivity. These results highlight the promise of conservation tillage and nano-fertilizer technology as environmentally friendly options for enhancing resource efficiency and resilience of dryland crop production systems in Uttar Pradesh's Central Plain Zone.

Keywords: Finger millet (*Eleusine coracana* L.), zero tillage, nano-fertilizer, soil moisture estimation, water use efficiency, nutrient management

1. Introduction

Finger millet (*Eleusine coracana* L.) is a climate-resilient small millet crop extensively grown in India's semi-arid and sub-humid tropics, extremely sought after because of its nutritional value, drought resistance, and tolerance to marginal soils (Rao *et al*., 2017; Kumar *et al*., 2021) [13, 6]. It is a significant rainfed agriculture food and fodder crop and a key source of food and livelihood security for small and marginal farmers (Yadav *et al*., 2020) [23]. But the downward trend in soil fertility, irregularity in rainfall distribution, and rising temperature fluctuations have negatively impacted soil moisture dynamics and water use efficiency (WUE) of finger millet cropping systems (Singh and Sharma, 2019) [16]. Impacts of water and nutrient stresses thus need to be minimized through efficient water and nutrient management in order to enhance productivity and water-use efficiency of this crop under water-limited situations. Agricultural practices like zero tillage, raised bed planting, and retaining residues have assumed greater significance as promising strategies to conserve soil health, save water, and prevent soil erosion (Jat *et al*., 2019; Thierfelder *et al*., 2021) [4, 20]. Zero tillage improves the soil structure, saves evaporation losses, and improves infiltration and soil organic carbon stock (Kumar *et al.*, 2020) [5]. In the same way, raised bed planting also delivers enhanced aeration, root development, and drainage, factors that may affect the storage of soil water as well as yields in crops (Patel *et al*., 2022) [9]. In conjunction with effective management of nutrients, having such conservation activities was noted to maximize the storage of soil water and crop water productivity in rainfed systems (Srinivasarao *et al.,* 2018) [18]. Nutrient management is the key driver of soil-plant-water balance maintenance by impacting root growth and nutrient use efficiency of uptake (Verma *et al.,* 2021) [21]. Integrated and balanced fertilizer application improves the water uptake potential of the plant, thus improving WUE (Singh *et al.,* 2018) [17]. During the recent decades, innovation of nano-fertilizers like nano urea and nano DAP has provided prospects for greater fertilizer-use efficiency and loss reduction from conventional fertilizers (Choudhary *et al*., 2021) [2]. Nano-fertilizers allow nutrient delivery with precise targeting and accuracy, improve nutrient uptake, and optimize physiological water use by plants (Prasad *et al.,* 2017: Natarajan *et al*., 2022) [12, 7]. Investigation of nano-fertilizers in conjunction with prevailing nutrient conservation and management practices can consequently result in improved water holding capacity of soils and water use efficiency in cereal crop production systems (Patil *et al*., 2023) [10]. The Central Plain Zone in Uttar Pradesh, which is medium in rainfall and has clay loam soils, provides an appropriate scenario to study the collective effect of conservation and nutrient management practices on soil moisture as well as WUE. But limited research involves conservation tillage, raised bed method, and nano-based nutrient management in finger millet under this region. Thus, the current study was undertaken to assess the role of conservation practice and nutrient management on soil moisture estimation (mm) and water use efficiency (kg ha^{-1} mm^{-1}) in finger millet (*Eleusine coracana* L.) under Central Plain Zone of Uttar Pradesh. The study aims to provide a scientific basis for improving water and nutrient-use efficiency, and promoting sustainable millet production systems under rainfed environments.

2. Materials and Methods

2.1 Experimental Location and Climatic Condition

Experiments were undertaken on-field during 2023 and 2024 kharif seasons at the Soil Conservation and Water Management Farm, Students' Instructional Farm, Chandra Shekhar Azad University of Agriculture & Technology (CSAUA&T), Kanpur, Uttar Pradesh, India (25°26-26°58′ N; 79°31-80°34′ E). The sub-tropical climate of the area receives an average annual rainfall of 800-830 mm, which mainly occurs during July-September. Weekly meteorological readings (maximum and minimum temperature, relative humidity, wind speed, rainfall, evaporation, and sunshine hours) in the university weather observatory for the two seasons are taken.

2.2 Characterization and sampling of soils

Experimental soil is alluvial, sandy loam, weak alkaline, and moderately fertile. Before laying out, composite surface soil samples (0-15 cm) were taken at random using a soil auger, air-dried, powdered lightly, and passed through a 2 mm sieve. Physical fractions by pipette technique of international pipette (Piper, 1966) [11]; bulk density by core technique of Blake (1965) [1]; particle density by Richards (1954) [14]; organic carbon by Walkley-Black (Jackson, 1967) [3]; available N by alkaline $KMnO_4$ (Subbiah & Asija, 1956) [19]; available P by Olsen's method of Olsen *et al*. (1956) [8]; and available K by flame photometry of Jackson (1967) [3].

2.3 Experimental layout, treatments, and crop

The trial was conducted using a factorial randomized block design (FRBD) with 3 replications considering three conservation practices (C) and six nutrient management treatments (F) as indicated in Table 1. Plot dimensions were gross 5.0 m × 4.2 m (21 m²) and net 4.0 m × 3.0 m (12 m²) with 30 cm row spacing and 1 m main irrigation channel. Test crop was finger millet (ragi) variety KM-65 (CSAUA&T, Kanpur). The optimal dose of fertilizers for the region was 60:30:30 kg $N:P_2O_5$: K_2O ha^{-1} unless altered by the nutrient treatments.

2.4 Crop establishment and field operations

Land preparation was as per institutional practice and treatment requirements. For normal tillage, one deep discing was preceded by two cultivator and planking passes; zero tillage plots were planted with least soil disturbance; raised beds were prepared as per standard practice for millet. Planting was done in early June each year to coincide with monsoon onset. Row spacing was 30 cm; seeds of KM-65 were procured from the university seed unit.

For fertilizers, one-third N as full P and K were placed basally at sowing; rest of N top-dressed in two equal splits at tillering and panicle initiation. Intercultural activities consisted of thinning 14 DAS and two weedings (15 and 35 DAS). Watering was supplied as supplemental depending on monsoon, generally 2-3 irrigations to prevent water stress at sensitive stages (especially flowering and earhead formation). Need-based protection with profenophos 50 EC @ 2 ml L^{-1} against sucking insects preceded the pest management. Harvest was threshed by hand, sun dried and plot-wise cut at 75-80% earhead yellowing; grain yield at 14% moisture content was recorded.

2.5 Soil Moisture measurement and observation

Low number of observations of finger millet includes, for example, estimation of soil moisture during crop growth stage and water use efficiency (WUE) was determined as grain yield (kg ha^{-1}) water uptake by the crop through its lifecycle and more studies on other characters.

2.5.1 Soil Moisture Estimation

Soil water content at various growth stages of the crop in finger millet was measured using the gravimetric method. Soil samples were collected by random sampling of five plants per plot at three levels, i.e., 0-15 cm, 15-30 cm, and 30-45 cm. Fresh weights of soil samples were harvested immediately and oven-dried at 105 ± 1°C to constant weight. The fresh weight at harvest - oven-dry weight difference was utilized to calculate the percentage of soil moisture. This technique gave a good evaluation of the soil water available during the entire crop growth duration.

2.5.2 Water Use Efficiency (WUE)

For finger millet, water use efficiency (WUE) was determined as grain yield (kg ha^{-1}) divided by total water utilisation (mm), including effective rainfall as well as soil moisture depletion over the entire crop duration. WUE was reported in kg ha^{-1} mm^{-1}.

The most frequently used formula for agricultural applications is:

Statistical analysis

The soil moisture estimation data (mm) at various crop growth stages were subjected to analysis based on the factorial randomized block design (FRBD) with treatment factors being conservation practices (C) and nutrient management (F) having three replications. ANOVA was conducted separately for both years, and pooled analysis over the years (2023 and 2024) was conducted after testing the homogeneity of error. Treatment means were established via least significant difference (LSD) test at 5% levels of significance ($P \leq 0.05$) to determine individual and interaction effects (C, F, and C×F). Normality and homogeneity of variance were tested in the data, and necessary transformations were done wherever necessary. OPSTAT software (Sheoran *et al*., 1998) [15] was used to analyze the data.

3. Results and Discussion

3.1 Soil Moisture Estimation (mm)

Soil moisture storage in finger millet (*Eleusine coracana* L.) was variably affected by conservation practices and nutrient management treatments during the kharif seasons of 2023 and 2024, and also on pooled mean basis (Table 2). Among the conservation farming practices, zero tillage (C_2) consistently recorded maximum soil moisture content in all the stages and years, followed by raised bed (C_3), while conventional tillage (C_1) had the minimum. In 2023, in zero tillage, 194.05 mm of soil moisture was preserved. It was also lower compared to conventional tillage, where 176.40 mm was preserved. However, in 2024, zero tillage recorded 477.61 mm of soil moisture against 434.18 mm in conventional tillage. Mean pooled wise, C_2 (335.83 mm) was greater than C_3 (320.55 mm) and C_1 (305.29 mm). Increased storage of soil moisture in zero tillage can be attributed to less disturbance of soil, enhanced aggregation, and increased infiltration capacity, which restrained evaporation losses. The same results were reported by Kumar *et al*. (2020) [5] and Thierfelder *et al*. (2021) [20], who reported increased soil-water retention in conservation tillage due to higher residue cover and soil structural stability. Soil nutrient management practices also significantly contributed. The maximum storage of soil moisture was attained by the treatment F_5 (100% NPK + Nano urea + Nano DAP) with a pooled mean of 331.66 mm, followed by F_4 (75% N & P + 100% K + Nano urea + Nano DAP), and the minimum was in F_1 (RDF for NPK) and F_6 (50% RDF + Nano urea + Nano DAP). The growth increment under nano-fertilizer treatments may be ascribed to enhanced root proliferation and efficient nutrient uptake that stimulate soil aggregation along with water holding capacity. Prasad *et al*. (2017) [12] and Choudhary *et al.* (2021) [2] also reported an improved soil moisture status in terms of increased nutrient-use efficiency and reduced loss of nutrients by applying nano-fertilizers.

3.2 Water Use Efficiency (kg ha^{-1} mm^{-1})

Water use efficiency (WUE) of finger millet was also significantly varied among the treatments (Table 3). Among the conservation practices, zero tillage (C_2) recorded the highest WUE, followed by conventional tillage (C_1), whereas raised bed (C_3) recorded the lowest. In 2023, zero tillage yielded 10.85 kg ha^{-1} mm^{-1} of WUE, compared to 9.08 kg ha^{-1} mm^{-1} in conventional tillage. The same pattern was seen in 2024 when zero tillage possessed 24.35 kg ha^{-1} mm^{-1}, having a pooled mean of 17.60 kg ha^{-1} mm^{-1}. These results are in favor of Singh and Sharma (2019) [16] and Jat *et al*. (2019) [4], who also showed higher WUE in zero-tillage plots owing to improved soil-moisture conservation and reduced surface evaporation. For the management of nutrients, F_6 (50% RDF + Nano urea + Nano DAP) showed the highest WUE (16.51 kg ha^{-1} mm^{-1}, pooled), followed by F_4 (15.64 kg ha^{-1} mm^{-1}), and the lowest was F_5 (14.34 kg ha^{-1} mm^{-1}). The higher WUE of F_6 under improved physiological efficiency of nano-formulations for raising nutrient uptake despite lower fertilizer application. Natarajan *et al*. (2022) [7] and Verma *et al*. (2021) [21] also depicted similar trends wherein they emphasized that nano-nutrients increase water productivity by coordinating the release of nutrients with the demand of the crop.

Table 1: Treatment details of conservation practices and nutrient management in finger millet

Factor	Treatment code	Treatment description
Conservation practices (C)	C_1	Conventional tillage
	C_2	Zero tillage
	C_3	Raised bed
Nutrient management (F)	F_1	RDF for NPK (60:30:30 kg ha^{-1})
	F_2	75% N of RDF + RDF of P & K + Nano urea
	F_3	100% N + 75% P + 100% K + Nano DAP
	F_4	75% N & P + 100% K + Nano urea + Nano DAP
	F_5	100% NPK + Nano urea + Nano DAP
	F_6	50% RDF + Nano urea + Nano DAP

Table 2: Effect of different treatments in Soil moisture estimation of finger millet

Treatments	Soil moisture estimation		Pooled
	2023	2024	
Conservation practices(C)			
C_1 Conventional tillage	176.40	434.18	305.29
C_2 Zero tillage	194.05	477.61	335.83
C3 Raised bed	185.20	455.91	320.55
Nutrient management(F)			
F_1 -RDF for NPK	180.70	444.80	312.75
F_2 -75% N of RDF + RDF of Phosphorus and Potash + Nano Urea	186.13	457.80	321.96
F_3- 100% N + 75% Phosphorus + 100% Potash + Nano DAP	184.29	453.70	318.99
F_4 -75% N & P + 100% Potash + Nano urea and Nano DAP	187.93	462.56	324.96
F_5 - 100% NPK + Nano urea and Nano DAP	191.53	471.80	331.66
F_6 - 50% RDF + Nano urea and Nano DAP	180.70	444.76	312.73

Table 3: Effect of different treatments water use efficiency of finger millet

Treatments	Water use efficiency		Pooled
	2023	2024	
Conservation practices(C)			
C_1 Conventional tillage	9.08	20.19	14.63
C_2 Zero tillage	10.85	24.35	17.60
C3 Raised bed	8.62	19.65	14.13
Nutrient management(F)			
F_1 -RDF for NPK	9.33	21.01	15.17
F_2 -75% N of RDF + RDF of Phosphorus and Potash + Nano Urea	9.39	21.15	15.27
F_3- 100% N + 75% Phosphorus + 100% Potash + Nano DAP	9.07	20.77	14.92
F_4 -75% N & P + 100% Potash + Nano urea and Nano DAP	9.66	21.62	15.64
F_5 - 100% NPK + Nano urea and Nano DAP	8.88	19.80	14.34
F_6 - 50% RDF + Nano urea and Nano DAP	10.76	22.27	16.51

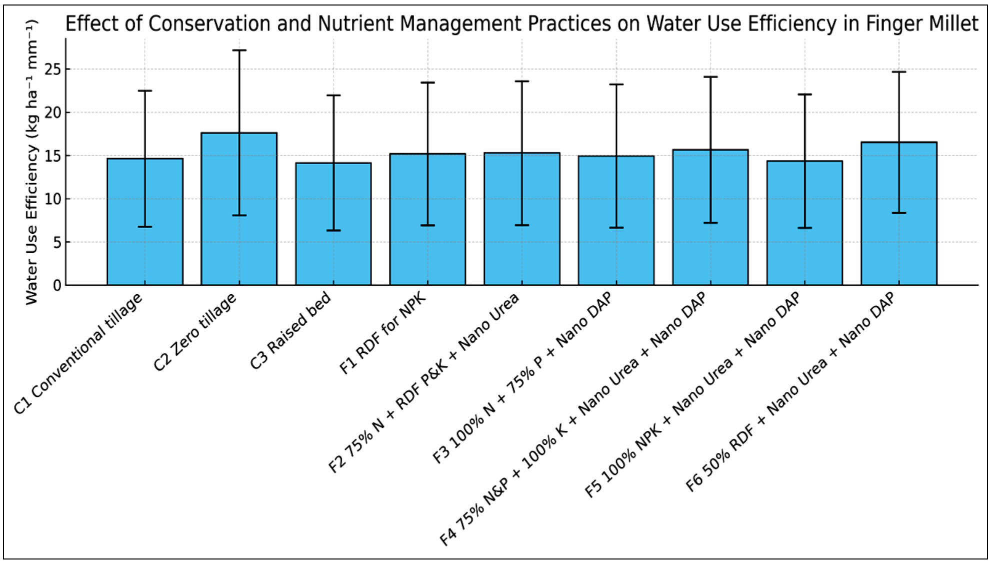

Fig 1: Effect of different treatments in Soil moisture estimation of finger millet

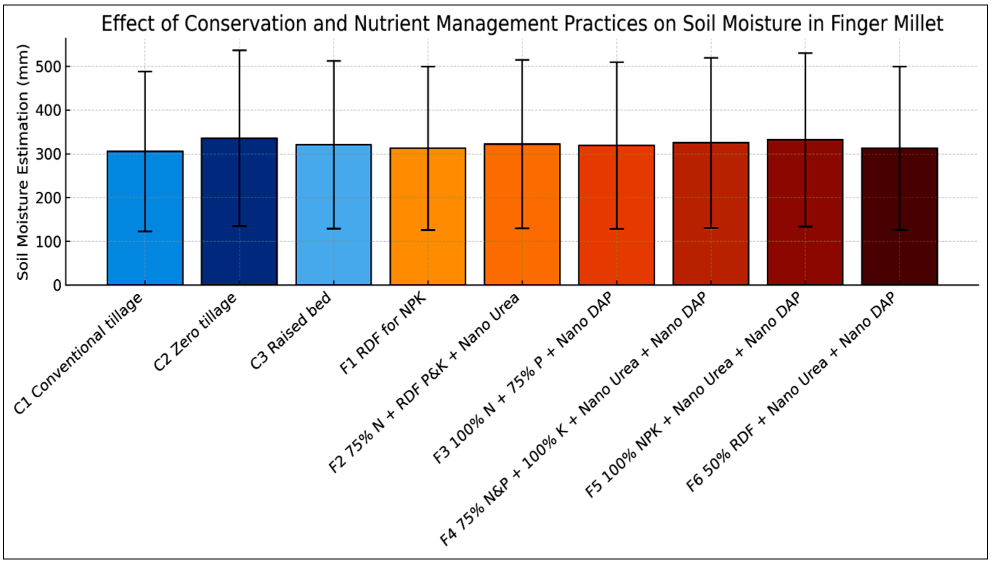

Fig 2: Effect of different treatments water use efficiency of finger millet

4. Conclusion

The study was confirmed as conservation practices and nutrient management practices significantly influenced the soil water retention and water use efficiency (WUE) of finger millet under the Central Plain Zone of Uttar Pradesh. Of the conservation methods, zero tillage (C_2) contained maximum soil moisture at all times and it exhibited improved WUE, which signifies its ability to enhance water conservation and resource-use efficiency in rainfed as well as semi-arid conditions. Similarly, nutrient management with nano-based fertilizers greatly improved soil-water relationship and productivity. Maximum storage of soil moisture was observed with treatment F_5 (100% NPK + Nano urea + Nano DAP), and the maximum WUE with less fertilizer application was observed with treatment F_6 (50% RDF + Nano urea + Nano DAP), demonstrating the efficacy and sustainability of nano-nutrient formulations. The combined implementation of zero tillage and nano-fertilizer-based nutrient management is a possible, eco-efficient pathway towards the optimization of soil water balance, enhanced nutrient uptake, and overall water productivity in finger millet systems. The mentioned combined practices can be recommended for sustainable intensification of dryland cropping in the Central Plain Zone of Uttar Pradesh.

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