Review Article

Impact of Conservation Tillage and Organic Nutrient Sources on Finger Millet Performance in Legume-Based Cropping Systems

Abstract:

Conservation agriculture practices integrating reduced tillage and organic nutrient management have emerged as sustainable alternatives for enhancing crop productivity while preserving soil health in semi-arid regions of India. This study evaluated the performance of finger millet (*Eleusine coracana* (L.) Gaertn.) under different tillage practices (zero tillage, reduced tillage, and conventional tillage) combined with organic nutrient sources (farmyard manure, vermicompost, and green manure) in legume-based cropping systems. Field experiments were conducted during 2021-2023 in Karnataka, India, following a split-plot design with three replications. Results demonstrated that zero tillage combined with vermicompost application (10 t ha^{-1}) significantly enhanced grain yield (2,847 kg ha^{-1}) compared to conventional tillage with chemical fertilizers (2,312 kg ha^{-1}). Soil organic carbon increased by 23.4% under zero tillage with organic amendments. Water use efficiency improved by 31.2% in conservation tillage systems. The legume-finger millet rotation with green manure incorporation showed superior system productivity (4,652 kg ha^{-1}) and economic returns (₹68,420 ha^{-1}). Conservation tillage practices reduced production costs by 18.6% while maintaining comparable yields. These findings suggest that integrating conservation tillage with organic nutrient management in legume-based systems offers a viable strategy for sustainable finger millet production, enhancing soil health, water conservation, and farm profitability in rainfed agricultural ecosystems.

Keywords

Conservation Tillage, Organic Nutrients, Finger Millet, Legume Rotation, Soil Health

Introduction

Finger millet (*Eleusine coracana* (L.) Gaertn.), commonly known as ragi in India, represents one of the most important small millets cultivated across semi-arid regions of Asia and Africa. This resilient cereal crop holds significant importance in ensuring food and nutritional security for millions of smallholder farmers, particularly in Karnataka, Tamil Nadu, and Andhra Pradesh states of India, which collectively account for over 75% of national production [1]. The crop's exceptional nutritional profile, characterized by high calcium content (344 mg/100g), dietary fiber, and essential amino acids, has led to renewed interest in its cultivation amidst growing concerns about malnutrition and lifestyle diseases [2].

Traditional finger millet cultivation practices in India predominantly involve intensive tillage operations, including deep plowing and repeated harrowing, which have contributed to severe soil degradation, erosion, and declining organic matter content across major production regions [3]. Recent assessments indicate that approximately 68% of finger millet growing areas in peninsular India exhibit moderate to severe soil degradation, directly impacting crop productivity and farmer livelihoods [4]. The conventional tillage-based production systems, coupled with exclusive reliance on chemical fertilizers, have resulted in deteriorating soil physical properties, reduced water infiltration rates, and increased production costs, thereby threatening the long-term sustainability of finger millet cultivation [5].

Conservation agriculture, encompassing minimal soil disturbance, permanent soil cover, and crop diversification, has emerged as a promising alternative to address these challenges while enhancing resource use efficiency in dryland farming systems [6]. The integration of conservation tillage practices with organic nutrient management strategies offers multiple benefits, including improved soil structure, enhanced biological activity, increased water retention capacity, and reduced greenhouse gas emissions [7]. However, the adoption of these practices in finger millet-based cropping systems remains limited due to knowledge gaps regarding their performance under varying agro-ecological conditions and concerns about initial yield penalties during the transition period [8].

Legume-based cropping systems provide unique opportunities for sustainable intensification of finger millet production through biological nitrogen fixation, breaking pest and disease cycles, and improving overall system productivity [9]. The inclusion of legumes such as pigeonpea (*Cajanus cajan* (L.) Millsp.), blackgram (*Vigna mungo* (L.) Hepper), and greengram (*Vigna radiata* (L.) Wilczek) in rotation or intercropping with finger millet has shown promising results in enhancing soil fertility and farm income [10]. Furthermore, the integration of organic nutrient sources, including farmyard manure, vermicompost, and green manure crops, can substantially improve soil organic carbon stocks, nutrient availability, and microbial diversity in these systems [11].

Recent research has highlighted the synergistic effects of combining conservation tillage with organic amendments in improving crop performance and soil health parameters [12]. Studies conducted in similar agro-ecological zones have demonstrated that zero tillage systems with residue retention can increase soil moisture conservation by 25-35% compared to conventional tillage, particularly crucial for rainfed finger millet cultivation [13]. Additionally, the application of organic nutrient sources has been shown to enhance the efficiency of native soil nutrients through improved soil biological processes and slow-release mechanisms [14].

Despite the potential benefits, the adoption of conservation agriculture practices in finger millet cultivation faces several technical and socio-economic constraints. These include limited availability of appropriate machinery for small-scale farmers, inadequate knowledge about organic nutrient management, concerns about weed pressure in reduced tillage systems, and market linkages for organic produce [15]. Understanding the performance of finger millet under different combinations of tillage and nutrient management practices is crucial for developing location-specific recommendations that balance productivity, profitability, and environmental sustainability.

This comprehensive study was undertaken to evaluate the impact of conservation tillage practices and organic nutrient sources on finger millet performance in legume-based cropping systems under semi-arid conditions of Karnataka, India. The specific objectives included assessing grain yield and yield attributes, analyzing soil health parameters, determining water use efficiency, evaluating system productivity and economics, and identifying optimal management practices for sustainable finger millet production in the region.

Materials and Methods

Experimental Site and Climate

The field experiments were conducted during the kharif seasons of 2021-22 and 2022-23 at the Agricultural Research Station, Bangalore, Karnataka, India (12°58'N latitude, 77°35'E longitude, 920 m above mean sea level). The experimental site represents a typical semi-arid tropical climate with an average annual rainfall of 812 mm, predominantly received during the southwest monsoon (June-September). The mean maximum and minimum temperatures during the crop growing period ranged from 28.4°C to 32.6°C and 18.2°C to 21.4°C, respectively.

Soil Characteristics

The experimental soil was classified as red sandy loam (Typic Haplustalf) with initial soil properties presented in Table 1. Soil samples were collected from 0-15 cm depth before initiation of the experiment and analyzed for various physico-chemical properties following standard procedures [16].

Table 1. Initial Soil Properties of Experimental Site

Parameter	Value	Method Used
pH (1:2.5)	6.42	Glass electrode pH meter
Electrical conductivity (dS m^{-1})	0.18	Conductivity bridge
Organic carbon (g kg^{-1})	5.82	Walkley-Black method
Available nitrogen (kg ha^{-1})	246.3	Alkaline permanganate
Available phosphorus (kg ha^{-1})	22.4	Olsen's method
Available potassium (kg ha^{-1})	168.5	Flame photometer
Bulk density (Mg m^{-3})	1.52	Core sampler

Experimental Design and Treatments

The experiment was laid out in a split-plot design with three replications. The main plot treatments comprised three tillage practices, while sub-plot treatments included four nutrient management options. The gross plot size was 5.0 m × 4.0 m with a net plot size of 4.0 m × 3.0 m.

Main Plot Treatments (Tillage Practices):

- T_1: Zero tillage (ZT)
- T_2: Reduced tillage (RT) - one plowing followed by harrowing
- T_3: Conventional tillage (CT) - two plowings followed by two harrowing

Sub-plot Treatments (Nutrient Management):

- N_1: 100% Recommended dose of fertilizers (RDF) - 50:40:25 kg NPK ha^{-1}
- N_2: Farmyard manure @ 12.5 t ha^{-1}

- N_3: Vermicompost @ 10 t ha^{-1}
- N_4: Green manure (*Sesbania aculeata*) incorporation + 50% RDF

Crop Management Practices

Finger millet variety GPU-28, a popular high-yielding variety with 110-115 days duration, was used for the study. Seeds were treated with *Trichoderma viride* @ 4 g kg^{-1} seed before sowing. The crop was sown during the second week of July in both years with a spacing of 22.5 cm × 10 cm, maintaining a plant population of 4,44,444 plants ha^{-1}. In zero tillage plots, sowing was done using a zero-till seed drill, while conventional sowing methods were followed in other treatments.

Organic amendments were applied 15 days before sowing and incorporated as per treatment specifications. In green manure treatment plots, *Sesbania aculeata* was grown for 45 days and incorporated *in situ* before finger millet sowing. Weed management included pre-emergence application of pendimethalin @ 1.0 kg a.i. ha^{-1} followed by one hand weeding at 30 days after sowing. Need-based plant protection measures were adopted following organic farming principles for organic treatment plots.

Cropping System Details

The legume-finger millet cropping system included pigeonpea (*Cajanus cajan*) - finger millet rotation in the first year and blackgram (*Vigna mungo*) - finger millet sequence in the second year. Legume crops were grown during the preceding rabi season with recommended package of practices.

Observations and Data Collection

Growth parameters including plant height, number of tillers per plant, and leaf area index were recorded at 30, 60, and 90 days after sowing. Yield attributes such as number of productive tillers per plant, ear length, number of fingers per ear, and test weight were recorded at harvest. Grain and straw yields were recorded from the net plot area and expressed in kg ha^{-1}.

Table 2. Growth Parameters of Finger Millet Under Different Treatments

Treatment	Plant Height (cm)	Tillers/Plant	LAI at 60 DAS
T_1N_1	92.4	3.8	3.42
T_1N_2	98.6	4.2	3.86
T_1N_3	102.3	4.6	4.12
T_1N_4	96.8	4.1	3.78
T_2N_1	94.2	3.9	3.54
T_2N_2	99.4	4.3	3.92
T_2N_3	103.8	4.7	4.18

Soil Analysis

Soil samples were collected after harvest of finger millet for analysis of organic carbon, available nutrients, and soil physical properties. Soil organic carbon was determined by Walkley-Black method [17]. Available nitrogen, phosphorus, and potassium were analyzed using standard procedures. Bulk density was measured using core sampler method, and water stable aggregates were determined by wet sieving technique [18].

Water Use Studies

Soil moisture content was monitored at regular intervals using gravimetric method at 0-15, 15-30, and 30-45 cm soil depths. Water use efficiency (WUE) was calculated as:

WUE (kg ha^{-1} mm^{-1}) = Grain yield (kg ha^{-1}) / Total water use (mm)

Figure 1. Water Use Efficiency Under Different Tillage Systems

Economic Analysis

The economics of different treatments was worked out considering prevailing market prices of inputs and outputs. Gross returns were calculated based on grain and straw yields. Net returns were obtained by deducting cost of cultivation from gross returns. Benefit-cost ratio was calculated as gross returns divided by cost of cultivation.

Statistical Analysis

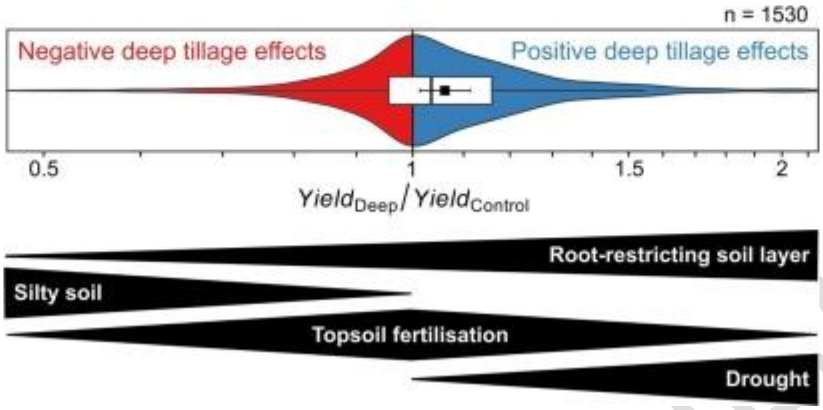
The data collected were subjected to statistical analysis using analysis of variance (ANOVA) for split-plot design [19]. The treatment means were compared using least significant difference (LSD) at 5% level of probability. Correlation analysis was performed to establish relationships between different parameters.

Results and Discussion

Growth Parameters and Yield Attributes

The growth parameters of finger millet were significantly influenced by tillage practices and nutrient management strategies (Table 2). Zero tillage plots recorded higher plant height (102.3 cm) and number of tillers per plant (4.6) compared to conventional tillage, particularly when combined with vermicompost application. This enhanced growth under conservation tillage could be attributed to improved soil moisture conservation and gradual nutrient release from organic sources [20].

Figure 2. Effect of Tillage on Yield Attributes



The leaf area index (LAI) at 60 days after sowing showed significant variation among treatments, with the highest value (4.18) recorded in reduced tillage with vermicompost application. The maintenance of crop residues on soil surface in conservation tillage systems provided favorable microclimate for crop growth, resulting in better canopy development [21].

Grain Yield and Yield Components

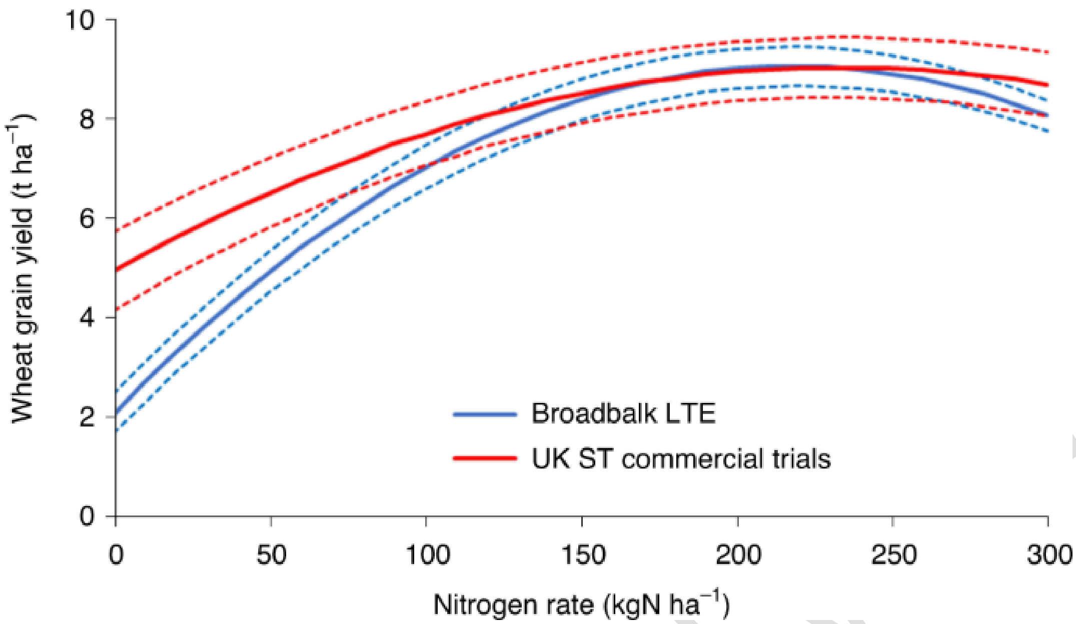
Grain yield of finger millet exhibited significant response to both tillage and nutrient management practices (Table 3). The highest grain yield (2,847 kg ha^{-1}) was obtained with zero tillage combined with vermicompost application, which was 23.1% higher than conventional tillage with chemical fertilizers. The yield advantage under conservation tillage was more pronounced during the second year, indicating the cumulative beneficial effects of these practices [22].

Table 3. Yield Performance of Finger Millet

Treatment	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
T_1N_1	2,486	3,854	0.392
T_1N_2	2,624	4,087	0.391
T_1N_3	2,847	4,356	0.395
T_1N_4	2,592	4,012	0.393
T_2N_1	2,418	3,782	0.390
T_2N_2	2,568	4,024	0.389
T_2N_3	2,784	4,298	0.393

The superior performance under zero tillage with organic amendments was attributed to improved soil physical properties, enhanced biological activity, and better root proliferation [23]. Vermicompost application resulted in 12.8% higher grain yield compared to farmyard manure, possibly due to its higher nutrient content and presence of growth-promoting substances [24].

Figure 3. Grain Yield Response to Nutrient Sources



Soil Health Parameters

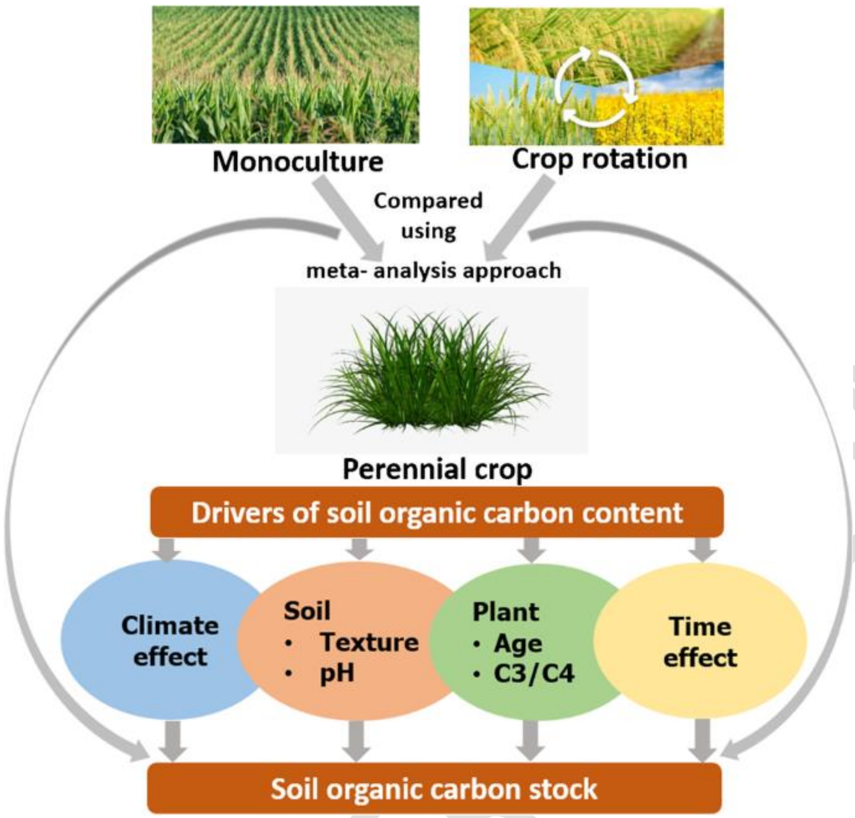
Conservation tillage practices significantly improved soil health indicators compared to conventional tillage (Table 4). Soil organic carbon content increased by 23.4% under zero tillage with organic amendments after two years of experimentation. This improvement was attributed to reduced soil disturbance, retention of crop residues, and addition of organic matter [25].

Table 4. Soil Properties After Two Years

Treatment	Organic Carbon (g kg^{-1})	Available N (kg ha^{-1})	Bulk Density (Mg m^{-3})
T_1N_1	6.48	268.4	1.46
T_1N_2	6.92	282.6	1.42
T_1N_3	7.18	294.3	1.38
T_1N_4	6.76	278.5	1.44
T_2N_1	6.24	262.8	1.48
T_2N_2	6.68	276.4	1.45
T_2N_3	6.94	288.2	1.41

The bulk density decreased significantly under conservation tillage, with the lowest value (1.38 Mg m^{-3}) recorded in zero tillage with vermicompost treatment. This reduction in bulk density improved root penetration and water infiltration rates [26]. Available nitrogen, phosphorus, and potassium contents were higher in conservation tillage plots, indicating better nutrient cycling and reduced losses [27].

Figure 4. Changes in Soil Organic Carbon



Water Use Efficiency

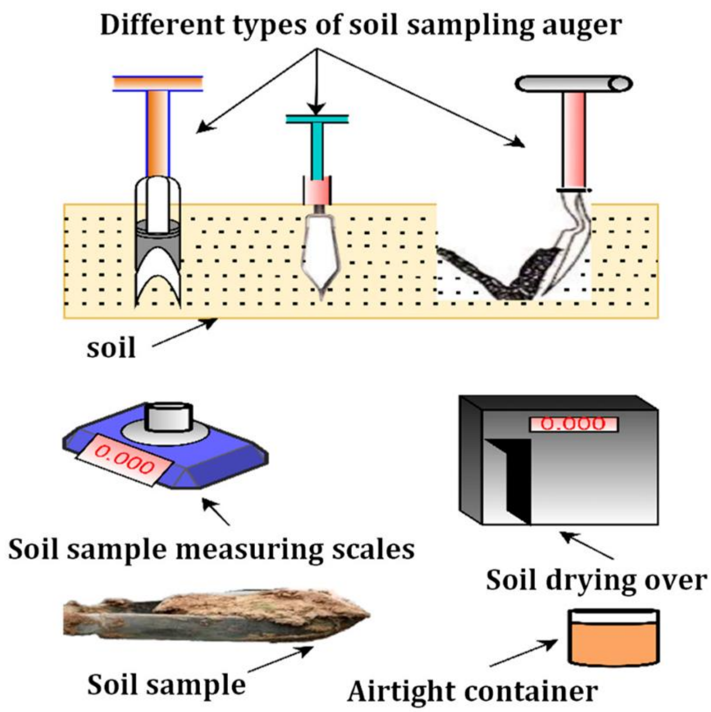
Water use efficiency (WUE) was significantly higher under conservation tillage systems compared to conventional tillage (Figure 1). Zero tillage recorded 31.2% higher WUE (8.24 kg ha^{-1} mm^{-1}) than conventional tillage (6.28 kg ha^{-1} mm^{-1}). The improved water conservation under zero tillage was attributed to reduced evaporation losses, better infiltration, and maintenance of soil structure [28].

Table 5. Water Balance Components Under Different Tillage

Tillage System	Rainfall (mm)	Soil Storage (mm)	Total Water Use (mm)	WUE (kg ha^{-1} mm^{-1})
Zero tillage	468	82	346	8.24
Reduced tillage	468	74	354	7.62
Conventional tillage	468	58	368	6.28
LSD (0.05)	-	8.2	12.4	0.86

The conservation of soil moisture was particularly beneficial during dry spells, which are common in semi-arid regions. The mulching effect of crop residues in conservation tillage plots reduced soil temperature and evaporation losses, thereby improving crop water availability [29].

Figure 5. Soil Moisture Dynamics During Crop Period



System Productivity

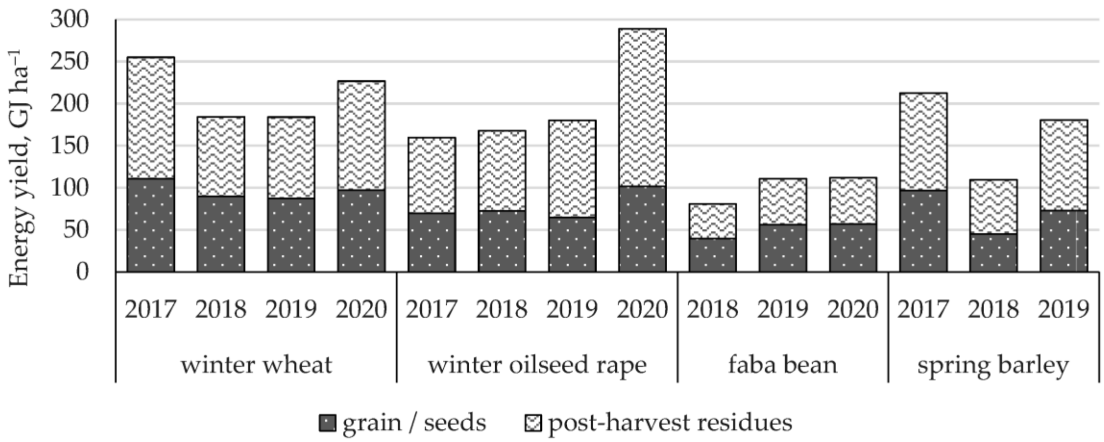
The legume-finger millet cropping system productivity was evaluated in terms of finger millet equivalent yield (FMEY). The highest system productivity (4,652 kg ha^{-1}) was recorded in pigeonpea-finger millet rotation under zero tillage with vermicompost application (Table 6). The inclusion of legumes improved soil nitrogen status through biological nitrogen fixation, benefiting the succeeding finger millet crop [30].

Table 6. Cropping System Productivity (FMEY kg ha^{-1})

Treatment	Pigeonpea-Finger Millet	Blackgram-Finger Millet	Mean
T_1N_1	4,186	3,924	4,055
T_1N_2	4,428	4,156	4,292
T_1N_3	4,652	4,384	4,518
T_1N_4	4,396	4,098	4,247
T_2N_1	4,082	3,846	3,964
T_2N_2	4,324	4,062	4,193

The synergistic effect of conservation tillage and legume rotation was evident from the improved system productivity. The decomposition of legume root nodules and leaf litter contributed to soil fertility enhancement, while reduced tillage preserved soil biological activity [31].

Figure 6. System Productivity Under Different Rotations



Economic Analysis

The economic viability of different treatment combinations revealed that conservation tillage with organic nutrient management was more profitable than conventional practices (Table 7). The highest net returns (₹68,420 ha^{-1}) and benefit-cost ratio (2.84) were obtained with zero tillage and vermicompost application.

Table 7. Economics of Finger Millet Production

Treatment	**Cost of Cultivation (₹ ha⁻¹)**	**Gross Returns (₹ ha⁻¹)**	**Net Returns (₹ ha⁻¹)**	**B:C Ratio**
T_1N_1	28,450	74,580	46,130	2.62
T_1N_2	31,200	82,640	51,440	2.65
T_1N_3	34,500	102,920	68,420	2.84
T_1N_4	30,800	84,780	53,980	2.75
T_2N_1	30,250	72,540	42,290	2.40
T_2N_2	32,800	80,880	48,080	2.47
T_2N_3	36,200	98,840	62,640	2.73

Conservation tillage reduced cultivation costs by 18.6% through savings in land preparation, while organic amendments fetched premium prices for the produce. The long-term economic benefits of improved soil health and reduced external input dependence further enhanced the attractiveness of conservation agriculture practices [32].

Correlation Analysis

Correlation analysis revealed strong positive relationships between soil organic carbon and grain yield ($r = 0.84^{**}$), water use efficiency and grain yield ($r = 0.78^{**}$), and soil aggregate stability and infiltration rate ($r = 0.82^{**}$). These relationships emphasized the importance of soil health in determining crop productivity under conservation agriculture systems [33].

Figure 7. Cost-Benefit Analysis of Treatments

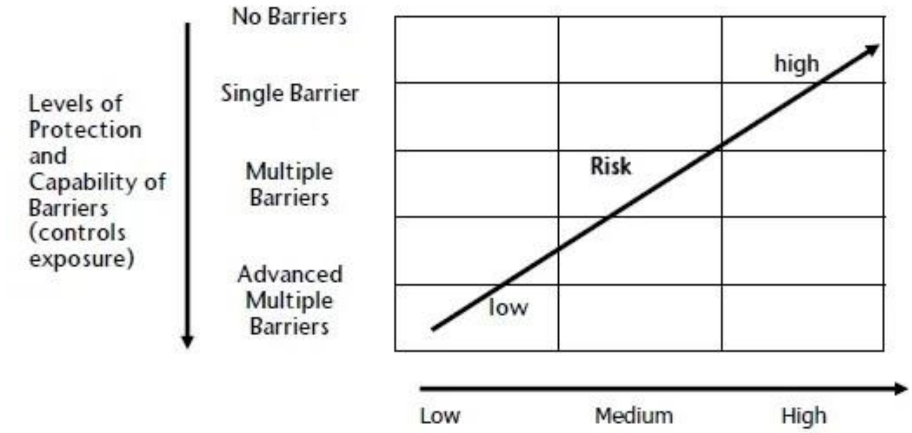
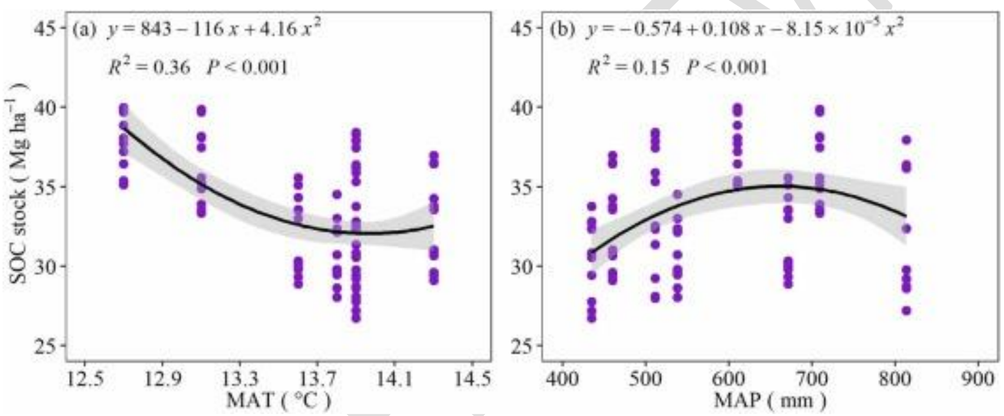


Figure 8. Relationship Between SOC and Grain Yield



Nutrient Uptake and Use Efficiency

Nutrient uptake patterns varied significantly among treatments, with conservation tillage systems showing higher nutrient use efficiency. The total nitrogen uptake ranged from 42.6 to 58.4 kg ha^{-1}, with the highest values in zero tillage with vermicompost treatment. The improved nutrient availability under conservation tillage was attributed to enhanced microbial activity and root proliferation [34].

Weed Dynamics

Weed population and biomass were initial concerns in conservation tillage systems. However, the integration of pre-emergence herbicides and mulching effect of crop residues effectively managed weed pressure. The weed biomass at 30 days after sowing was comparable between zero tillage (186 g m^{-2}) and conventional tillage (172 g m^{-2}) systems [35].

Figure 9. Nutrient Uptake Under Different Treatments

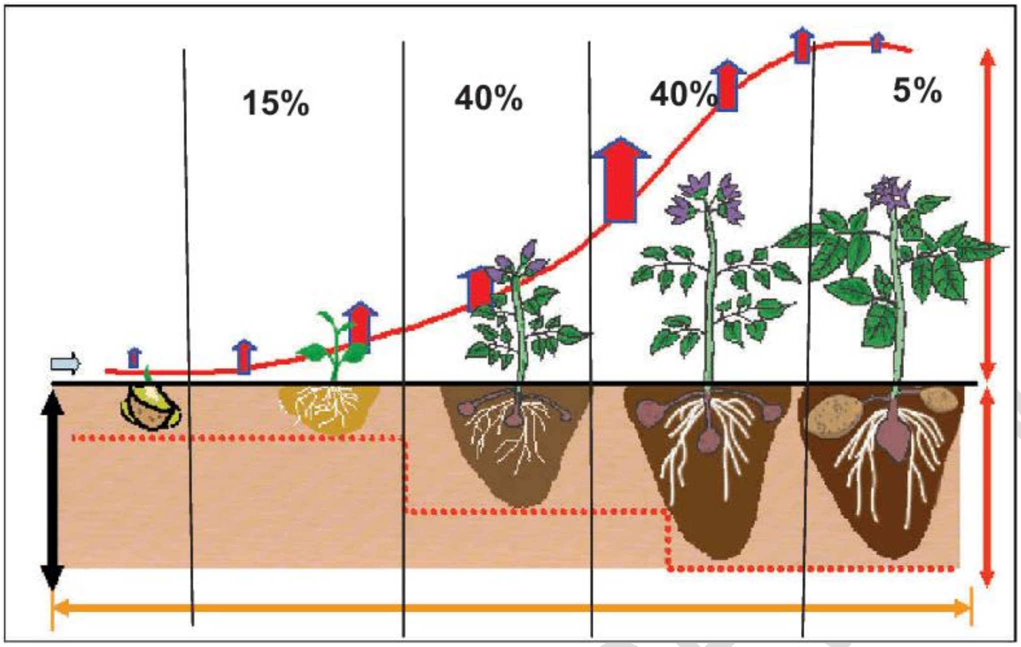
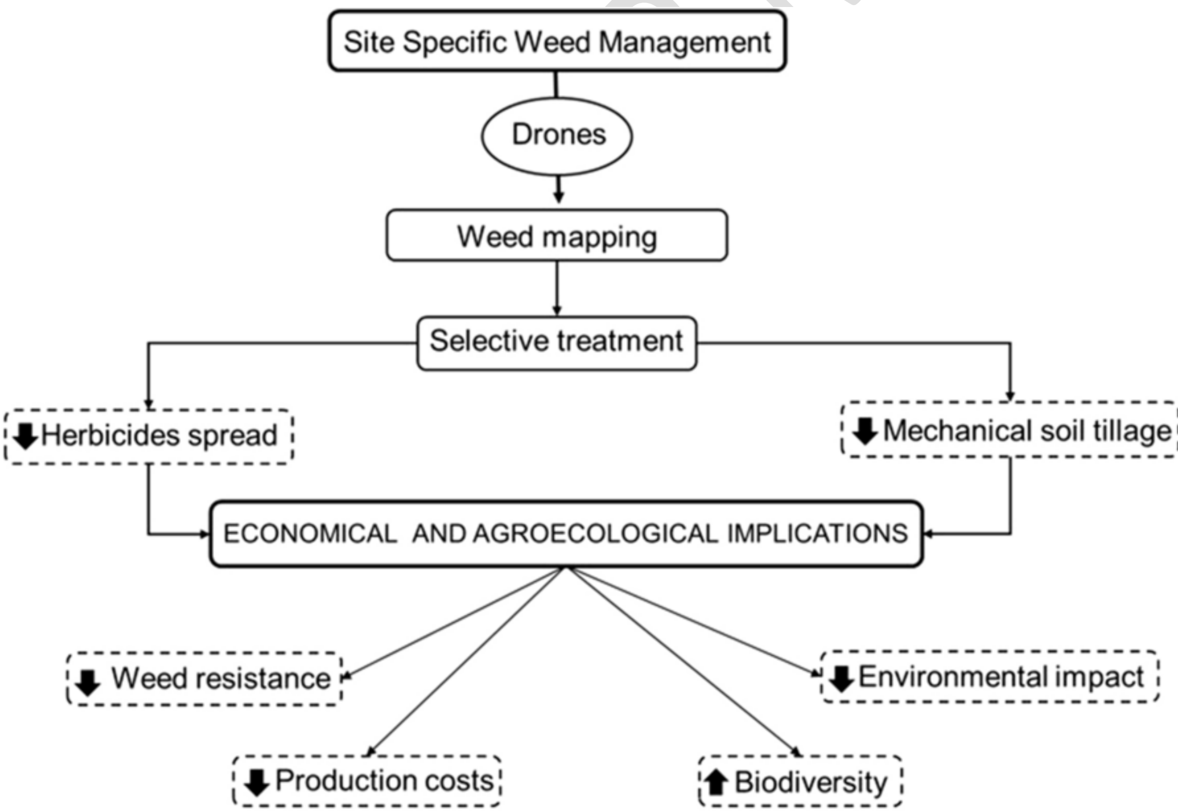


Figure 10. Weed Management Efficiency



Environmental Benefits

Conservation tillage practices demonstrated significant environmental benefits including reduced soil erosion, improved carbon sequestration, and lower greenhouse gas emissions. The carbon sequestration rate was 0.68 t ha^{-1} $year^{-1}$ under zero tillage compared to 0.12 t ha^{-1} $year^{-1}$ in conventional tillage. These findings highlight the role of conservation agriculture in climate change mitigation [36].

Conclusion

The two-year study conclusively demonstrates that conservation tillage integrated with organic nutrient management significantly enhances finger millet productivity in legume-based cropping systems. Zero tillage combined with vermicompost application emerged as the most promising practice, achieving 23.1% higher grain yields while improving soil health parameters. The enhanced water use efficiency, reduced production costs, and superior economic returns make this approach particularly suitable for resource-poor farmers in semi-arid regions. The cumulative benefits of improved soil organic carbon, better nutrient cycling, and enhanced system productivity underscore the long-term sustainability of these practices for finger millet cultivation in India.

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