Original Research Article

WEED DYNAMICS AND SOIL HEALTH AS INFLUENCED BY TILLAGE METHOD AND ESTABLISHMENT METHOD IN SMALL MILLETS

ABSTRACT

Summer rice fallows are the potential areas for crop diversification with millets. A field experiment on "Millets for crop diversification in summer rice fallows under minimum tillage" was conducted at Integrated Farming System Research Station (IFSRS), Karamana during summer season of 2023-24. The field experiment was laid out in split-split plot design with 12 treatment combinations and three replications. The main plot treatments were tillage method (M_1-minimum tillage and M_2- conventional tillage), sub plot treatments were crops (C_1-little millet, C_2-foxtail millet and C_3-proso millet) and the sub-sub plot treatments were establishment methods(P_1- solid row planting and P_2- broadcasting). The study indicated that grasses were the predominant weedflora in summer fallows and the lowest weed density and weed dry weight were observed in conventional tillage method with solid row planting. Among the establishment method, the highest N, P and K removal by weeds was recorded in broadcasting method (134.52 kg ha^{-1}, 4.38 kg ha^{-1} and 10.29 kg ha^{-1}, respectively). The results revealed that the highest organic carbon (2.09 %), available N and P were recorded in minimum tillage and solid row planting. It can be concluded from the study that minimum tillage with solid row planting enhanced the soil health while conventional tillage with solid row planting is a viable option for weed management of small millets in summer rice fallows.

***Keywords**: Diversification; Minimum tillage; Small millets; Soil health; Weed flora*

1. INTRODUCTION

Small millets are the new staple crops in the newera of climate change.Millets are sustainable food source for combating hunger in changing world climate[5].foxtail millet, little millet and proso millet were theprominent small millets that are said to be the most calming, least allergenic, and easily digested grains available.

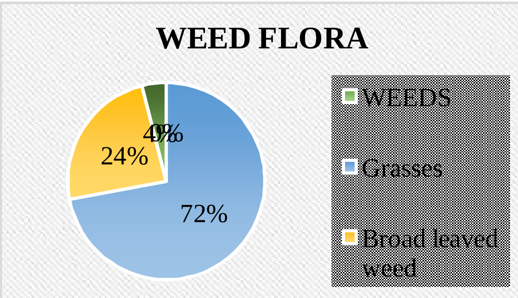
Millets are not very good competitors with weeds, especially in the early growth stages. Depending on climate, edaphic, and biotic variables, millets can experience yield losses from weeds ranging from 5 to 94 per cent [12].The critical period for millets typically occurs between15 and 42 days after sowing [4].

The number of weeds was greatly impacted by various tillage techniques. When compared to minimum and reduced tillage, conventional tillage dramatically decreased the population of weeds, regardless of the type of weed. Weed populations were significantly reduced as a result of the deeper positioning of weed seeds caused by conventional tillage, which prevented weeds from emerging from the soil[14].Tshering *et al*. (2022) reported that direct-seeded millet recorded a lower number of productive tillers (2.65 tillers/hill) which could be due to higher weed pressure during the initial growth stages. In transplanted millet, there was no overcrowding of seedlings, and weed pressure was considerably less.

Uncontrolled weed infestation significantly reduces the crop yield between and 15 to 83% in sorghum, 16 to 94% in pearl millet, and 55 to 61% in finger millet depending on crop cultivars, nature, and intensity of weed infestation, management practices, and environmental condition [7].

Conservation agriculture proved to be an excellent alternative to conventional agriculture in the long term of sustainable crop production and soil organic carbon sequestration [2]. Conservation agriculture practices involving zero tillage, crop residue management and suitable crop rotation can serve as a better alternative to conventional agriculture for maintaining soil quality.

Understanding the role of tillage in weed management for millet cultivation is critical for balancing effective weed control with sustainable soil management practices. As farmers face challenges from labour constraints, changing climates, and a need for more sustainable farming systems, the role of tillage in managing weeds for millet crops is evolving and requires careful consideration of its benefits and limitations.



2. MATERIALS AND METHODS

The field study was conducted at Integrated Farming System Research Station (IFSRS), Karamana, Thiruvananthapuram, Kerala, India during summer season of 2023-24. The experimental site was positioned at an elevation of 5 meters above mean sea level on soil p^H 5.7, bulk density 1.46 Mg m^{-3} and organic carbon 1.6%. Theavailable nitrogen, phosphorus and potassium recorded was 188.16 kg ha^{-1} ,23.5 kg ha^{-1} and158.83 kg ha^{-1}, respectively.A total rainfall of 674.88 mm was recorded during the study. The maximum and minimum temperature recorded during the study was 33.49^0 and 25.07^0C, respectively.

The experiment was laid out in split-split plot design with 12 treatment combinations and three replications. The main plot treatment was tillage (M_1- minimum tillage and M_2- Conventional tillage), the sub plot treatment was crop (C_1 – little millet, C_2 – foxtail millet and C_3- proso millet) and the sub-sub plot treatment was establishment method (P_1: solid row planting and P_2: Broadcasting).

In minimum tillage, the field will be ploughed once and seed bed will be taken retaining the crop residues of the previous crop of rice. In conventional tillage, the field will be ploughed thrice followed by secondary tillage without the crop residues. Solid row planting was done with inter row spacing of 25cm and plants were thinned at 10 DAS to maintain an intra-row spacing of 10 cm. ATL 1, DHFt-109-3 and TNAU 202 were the varieties used for the study for little millet, foxtail millet and proso millet, respectively. Farm yard manure and fertilizer application was done as per IIMR recommendations.ATL 1, DHFt-109-3 and TNAU 202 were the varieties used for the study for little millet, foxtail millet and proso millet, respectively.The crop was raised as a rainfed crop and one irrigation was given at 3 DAS and weeding operations were carried out manually at 30 DAS and 45 DAS.

3. RESULTS AND DISCUSSION

3.1 weed flora

The floristic composition of experimental site is given in Fig 1.Sixteen (16) weed species were observed in experimental filed. The predominant weed flora were grasses. The predominant species among grasses were *Echinochloa colona*, *Digitaria ciliaris*, *Isachne miliacea* and *Cynodon dactylon*. Among, broad- leaved weeds *Oldenlandia umbellate*, *Alternanthera sessilis* and *Euphorbia hirta*. *Cyperus iria* was predominant under sedges (Table 1)

Fig 1. Floristic composition of weed in the experimental field

Table 1. **Weed flora observed in the experimental site**

Scientific name	Common name	Family
Grasses		
Cynodondactylon	Bermuda grass	Poaceae
Digitaria ciliaris	Finger grass/ Henry's crabgrass	Poaceae
Echinochloacolona	Jungle rice	Poaceae
Isachnemiliacea	Blood grass	Poaceae
Setariabarbata	Bristly foxtail grass/ corn grass	
Broad leaved weeds		
Alternanthera sessilis	Sessile joyweed, carpet weed	Amaranthaceae
Boerhaaviadiffusa	Punarnava / Spreading hogweed	Nyctaginaceae
Cleome rutidosperma	Purple cleome	Capparaceae
Commelinabenghalensis	Benghal day flower	Commelinaceae
Euphorbia hirta	Asthma plant	Euphorbiaceae
Limnocharis flava	Yellow velvet leaf	Alismataceae
Ludwigia perennis	Perennial water primerose	Onagraceae
Oldenlandiaumbellata	Chay root	
Phyllanthus niruri	Seed- under- leaf/ Gale of the swind	Euphorbiaceae
Sedges		
Cyperus iria	Rice flat sedge/ Umbrella sedge	Cyperaceae
Fimbristylismiliacea	Fimbry/ Lesser fimbristylis	Cyperaceae

3.2 weed density and weed dry weight

Weed density was significantly influenced by tillage method at 15 DAS, 30DAS and 45 DAS (Table 2a and 2b, Fig.2). Weed density was the lowest (154.44, 56.33 and 12.44 no. m^{-2}, respectively) at conventional tillage method (M_2) and the highest at minimum tillage method (238.33, 75.94 and 23.72 no. m^{-2}, respectively). At 15 DAS, crop had significant influence on weed density. Lower weed density was observed in little millet (184.75 no. m^{-2}) and it was on par with foxtail millet (196.67 no. m^{-2}). Among the establishment method solid row planting recorded the lowest weed density (188.06, 60.67 and 14.72 no. m^{-2}) followed by broadcasting method. The possible reasons of higher weed incidence in broadcast seeding relative to drill seeding may be because of uneven/non-uniform crop stand in broadcast seeding compared to line-seeding manually or by drill [9].

The results revealed that tillage method and establishment method had significant influence on weed dry weight (Table 3a and 3b, Fig. 3). At 15 DAS, 30DAS and 45 DAS, the highest weed dry weight was recorded in minimum tillage (53.12 g m^{-2}, 68.50 g m^{-2} and 76.62 g m^{-2}, respectively).Among the establishment method, the highest weed dry weight was recorded in broadcasting method (46.21 g m^{-2}, 59.33 g m^{-2} and 67.28 g m^{-2}) at 15, 30 and 45 DAS. At 45 DAS, crop had significant effect on weed dry weight. The highest weight (64.25 g m^{-2}) was observed in proso millet and it was on par with foxtail millet.

Field ploughing move weed seeds bidirectionally, and change the soil properties and thereby altering weed seed germination [11]. Reduction in tillage operations as in minimum tillage increases the weed infestation. Tillage changes vertical distribution of weed seeds in soil profile and soil physical properties, and affects emergence and seed survival of weeds through changes in soil conditions and determines weed seedling emergence and species composition[6].Abid *et al*, (2019) reported that weed density and dry weight were lower under conventional tillage followed by hand weeding and minimum tillage followed by herbicide treatments in summer fallows cultivated with green gram.

Table 2a. Effects of treatments on weed density

Treatments	15DAS	30 DAS	45 DAS
Tillage method (M)			
M_1- Minimum tillage	238.33	75.94	23.72
M_2- Conventional tillage	154.44	56.33	12.44
SEm (±)	2.29	0.62	0.82
CD (0.05)	13.910	3.757	5.008
Crop (C)			
C_1 -Little millet	184.75	63.33	16.08
C_2 - Foxtail millet	196.67	70.00	19.33
C_3- Proso millet	207.75	65.08	18.83
SEm (±)	4.50	2.31	1.34
CD (0.05)	14.675	NS	NS
Establishment method (P)			
P_1 -Solid row planting	188.06	60.67	14.72
P_2 - Broadcasting	204.72	71.61	21.44
SEm (±)	2.20	2.24	0.76
CD (0.05)	6.790	6.899	2.347

Comment [GK1]: CD (P = 0.05)

Table 2b. INTERACTION EFFECTS OF TREATMENTS ON WEED DENSITY

Treatments	15 DAS	30 DAS	45 DAS
M×C			
M_1C_1	248.17	69.67	23.67
M_1C_2	218.33	86.00	24.33
M_1C_3	248.50	72.17	23.17
M_2C_1	121.33	57.00	8.50
M_2C_2	175.00	54.00	14.33
M_2C_3	167.00	58.00	14.50
SEm±	6.36	3.27	1.90
CD (0.05)	20.753	10.660	NS
M×P			
M_1P_1	230.33	70.33	18.78
M_1P_2	246.33	81.56	28.67
M_2P_1	145.78	51.00	10.67
M_2P_2	163.11	61.67	14.22
SEm±	3.12	3.17	1.08
CD (0.05)	NS	NS	3.319
C×P			
C_1P_1	173.17	57.17	12.17
C_1P_2	196.33	69.50	20.00
C_2P_1	188.83	64.17	16.33
C_2P_2	204.50	75.83	22.33
C_3P_1	202.17	60.67	15.67
C_3P_2	213.33	69.50	22.00
SEm±	3.82	3.88	1.32
CD (0.05)	NS	NS	NS
M×C×P			
$M_1C_1P_1$	236.67	64.33	17.67
$M_1C_1P_2$	259.67	75.00	29.67
$M_1C_2P_1$	212.33	79.00	20.00
$M_1C_2P_2$	224.33	93.00	28.67
$M_1C_3P_1$	242.00	67.67	18.67
$M_1C_3P_2$	255.00	76.67	27.67
$M_2C_1P_1$	109.67	50.00	6.67
$M_2C_1P_2$	133.00	64.00	10.33
$M_2C_2P_1$	165.33	49.33	12.67
$M_2C_2P_2$	184.67	58.67	16.00
$M_2C_3P_1$	162.33	53.67	12.67
$M_2C_3P_2$	171.67	62.33	16.33

SEm±	5.40	5.49	1.87
CD (0.05)	NS	NS	NS

Fig 2. Effect of treatment on weed density

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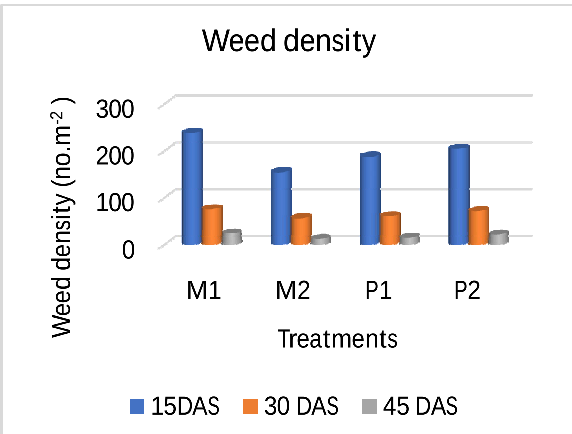


Table 3a. Effect of treatment on weed dry weight

Treatments	15DAS	30 DAS	45 DAS
Tillage method (M)			
M_1- Minimum tillage	53.12	68.50	76.62
M_2- Conventional tillage	33.61	39.97	45.40
SEm (±)	0.08	1.79	2.513
CD (0.05)	0.450	10.872	15.291
Crop (C)			
C_1 -Little millet	45.43	52.96	57.25
C_2 - Foxtail millet	43.68	55.58	61.54
C_3- Proso millet	41.00	54.17	64.25
SEm (±)	2.33	1.31	1.59
CD (0.05)	NS	NS	5.190
Establishment method (P)			
P_1 -Solid row planting	40.52	49.14	54.74
P_2 - Broadcasting	46.21	59.33	67.28
SEm (±)	0.80	1.43	1.28
CD (0.05)	2.467	4.416	3.933

Table 3b. Effect of treatment on weed dry weight

Treatments	15 DAS	30 DAS	45 DAS
M×C			
M_1C_1	57.35	68.67	68.32
M_1C_2	56.02	69.17	81.03
M_1C_3	46.00	67.67	80.51
M_2C_1	33.50	37.25	46.18
M_2C_2	31.33	42.00	42.05
M_2C_3	36.00	40.67	47.98
SEm±	3.29	1.85	2.25
CD (0.05)	NS	NS	7.34
M×P			
M_1P_1	51.38	60.67	69.77
M_1P_2	54.87	76.33	83.47
M_2P_1	29.67	37.61	39.71
M_2P_2	37.56	42.33	51.10
SEm±	1.13	2.03	1.81
CD (0.05)	NS	6.245	NS
C×P			
C_1P_1	41.28	45.75	48.43
C_1P_2	49.57	60.17	66.07
C_2P_1	39.45	51.67	56.82
C_2P_2	47.90	59.50	66.26
C_3P_1	40.83	50.00	58.97
C_3P_2	41.17	58.33	69.53
SEm±	1.39	2.48	2.21
CD (0.05)	4.274	NS	NS
M×C×P			
$M_1C_1P_1$	50.90	60.67	57.00
$M_1C_1P_2$	63.80	76.67	79.63
$M_1C_2P_1$	51.57	61.67	77.01
$M_1C_2P_2$	60.47	76.67	85.05
$M_1C_3P_1$	51.67	59.67	75.30
$M_1C_3P_2$	40.33	75.67	85.72
$M_2C_1P_1$	31.67	30.83	39.85
$M_2C_1P_2$	35.33	43.67	52.50
$M_2C_2P_1$	27.33	41.67	36.63
$M_2C_2P_2$	35.33	42.33	47.47
$M_2C_3P_1$	30.00	40.33	42.63
$M_2C_3P_2$	42.00	41.00	53.33
SEm±	1.96	3.51	3.13
CD (0.05)	6.044	NS	NS

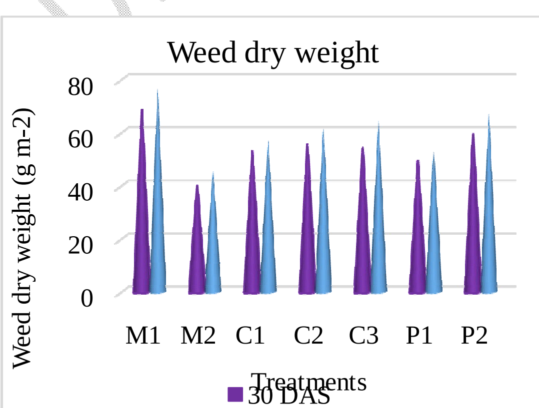


Fig 3. Effect of treatment on weed dry weight

Table 4b. Interaction effect of treatments on nutrient removal by weeds

Treatments	Nitrogen removal(kg ha^{-1})	Phosphorus removal (kg ha^{-1})	Potassium removal(kg ha^{-1})
M×C			

3.3 N, P and K removal by weeds

The results revealed that tillage method and establishment method had significant influence on N, P and K removal by weeds (Table 4a and 4b). Among the tillage method, the highest nitrogen and phosphorus and potassium removal was recorded in minimum tillage (165.37 kg ha^{-1}, 5.25 kg ha^{-1} and 12.34 kg ha^{-1}, respectively). Among the establishment method, the highest N, P and K removal was recorded in broadcasting method (134.52 kg ha^{-1}, 4.38 kg ha^{-1} and 10.29 kg ha^{-1}, respectively).This may be due to the highest dryweight of weeds in the treatments. Crop had significant influence on P and K removal by weed. The highest P removal (4.31 kg ha^{-1}) was recorded in proso millet and higher K removal (9.88 kg ha^{-1}) was also recorded in proso millet and it was on par with foxtail millet. The predominant grassy weeds caused more K removal by the weeds

At 30 DAS and 45 DAS, nitrogen content of weed was significantly influenced by tillage method. The highest nitrogen content was observed in minimum tillage method (1.86 and 2.16 %, respectively) followed by conventional tillage method (1.37 and 1.69 %, respectively). The crop residues in the minimum tillage resulted more nutrient in soil resulted in more nutrient uptake. At 30 DAS, phosphorus content of weed was significantly influenced by tillage method. The highest P content (0.35 %) was observed in minimum tillage method followed by conventional tillage method (0.31 %). Tillage method had significant influence on potassium content of weed at 30 DAS and 45 DAS. The highest value was observed in minimum tillage method (1.48 and 1.61%, respectively) followed by conventional tillage method (1.26 and 1.36%, respectively).This is due to the predominance of grassy weeds.

Table 4a. Effect of treatments on nutrient removal by weeds

Treatments	Nitrogen removal(kg ha^{-1})	Phosphorus removal (kg ha^{-1})	Potassium removal (kg ha^{-1})
Tillage method (M)			
M_1- Minimum tillage	165.37	5.25	12.34
M_2- Conventional tillage	76.29	2.70	6.20
SEm (±)	6.06	0.12	0.31
CD (0.05)	36.890	0.726	1.910
Crop (C)			
C_1 -Little millet	117.51	3.63	8.65
C_2 - Foxtail millet	119.52	3.98	9.29
C_3- Proso millet	125.45	4.31	9.88
SEm (±)	5.59	0.10	0.28
CD (0.05)	NS	0.318	0.926
Establishment method (P)			
P_1 -Solid row planting	107.14	3.57	8.25
P_2 - Broadcasting	134.52	4.38	10.29
SEm (±)	3.81	0.14	0.21
CD (0.05)	11.741	0.433	0.643

M_1C_1	154.99	4.59	11.06
M_1C_2	170.12	5.49	12.79
M_1C_3	170.99	5.65	13.15
M_2C_1	80.02	2.67	6.24
M_2C_2	68.93	2.46	5.78
M_2C_3	79.92	2.97	6.59
SEm±	7.90	0.14	0.40
CD (0.05)	NS	0.449	NS
M×P			
M_1P_1	147.57	4.90	11.05
M_1P_2	183.17	5.59	13.63
M_2P_1	66.70	2.24	5.45
M_2P_2	85.88	3.16	6.95
SEm±	5.39	0.20	0.30
CD (0.05)	NS	NS	NS
C×P			
C_1P_1	99.84	3.26	7.44
C_1P_2	135.18	4.00	9.86
C_2P_1	107.90	3.64	8.48
C_2P_2	131.14	4.31	10.09
C_3P_1	113.66	3.81	8.83
C_3P_2	137.25	4.81	10.91
SEm±	6.60	0.24	0.36
CD (0.05)	NS	NS	NS
M×C×P			
$M_1C_1P_1$	128.99	4.32	9.37
$M_1C_1P_2$	181.01	4.87	12.76
$M_1C_2P_1$	156.53	5.27	11.97
$M_1C_2P_2$	183.70	5.71	13.62
$M_1C_3P_1$	157.18	5.11	11.81
$M_1C_3P_2$	184.79	6.19	14.50
$M_2C_1P_1$	70.70	2.21	5.512
$M_2C_1P_2$	89.35	3.13	6.96
$M_2C_2P_1$	59.27	2.00	4.99
$M_2C_2P_2$	78.58	2.91	6.57
$M_2C_3P_1$	70.13	2.50	5.85
$M_2C_3P_2$	89.70	3.43	7.32
SEm±	9.33	0.34	0.51
CD (0.05)	NS	NS	NS

3.4 Plant uptake of nutrients

The tillage method had significant influence on K content. The highest K content was observed in conventional tillage method (3.06%) followed by minimum tillage method (2.96%).Among tillage method, the highest nutrient uptake (N, P and K) was observed in conventional tillage method (153.98, 28.57 and 110.83 kg ha^{-1}, respectively).It can be attributed due to better soil parameters due to conventional tillage. The lowest nutrient uptake was in minimum tillage method (130.75, 23.86 and 96.09 kg ha^{-1}, respectively).

Among the crop, highest nutrient uptake (N, P and K) was observed in little millet (175.56, 30.68 and 118.82 kg ha^{-1}, respectively). The lower nitrogen uptake was observed in proso millet (124.58 kg ha^{-1}) and it was at par with foxtail millet (126.95 kg ha^{-1}). The lower phosphorus uptake was observed in foxtail millet (23.94 kg ha^{-1}) and it was on par with proso millet (24.011 kg ha^{-1}). The lowest K uptake was observed in foxtail millet (92.53 kg ha^{-1}). Among the establishment method the highest nutrient uptake (N, P and K) was observed in broadcasting method of sowing (146.55, 26.98, and 106.28 kg ha^{-1}) followed by solid row planting (138.17, 25.44 and 106.28 kg ha^{-1}).

Among the interaction effects, tillage method and crop interaction were found to be significant on N and P uptake. The highest value was recorded in M_2C_1 interaction (195.26 and 33.86 kg ha^{-1}). P uptake was found to be significant on M×P interaction. The highest value was recorded in M_2P_2 interaction (29.31249 kg ha^{-1}). C×P interaction had significant influence on N and K uptake. The highest value was recorded in C_1P_2 interaction (186.33 and 127.93 kg ha^{-1}). M×C×P interaction was found to be significant on P uptake. The higher value was recorded in $M_2C_1P_2$ (34.63 kg ha^{-1}) and it was on par with $M_2C_1P_1$ interaction (33.08 kg ha^{-1}). Alam *et al*. (2023) reported that significantly the highest value of total N uptake, total P uptake and total K uptake were observed in conventional tillage.

3.4 Soil nutrient status

The soil bulk density decreased with degree of soil ploughing during tillage practices. From the experimental results it was observed that conventional tillage recorded the lowest bulk density of (1.42 Mg m^{-3}). Orzech *et al* (2021) reported that the changes in the bulk density and moisture content of soil varied across crop species, the developmental stages of plants, and soil horizons.

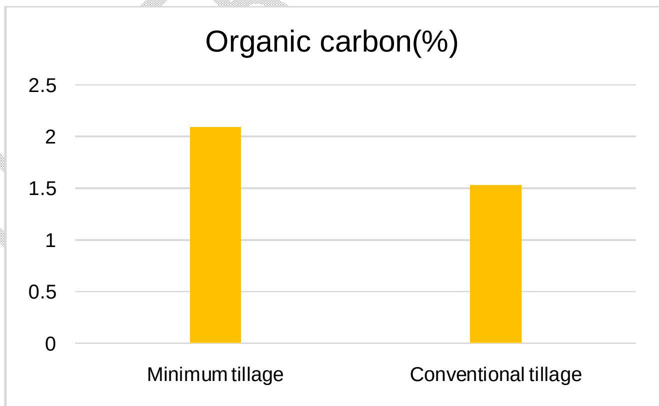
Soil organic carbon is an indicator of soil health and microbial activity. The minimum tillage method significantly affected the soil organic carbon content (Fig 4). The highest organic carbon content was observed in minimum tillage. This indicated that, compared to conventional tillage there was significant gain in soil organic carbon, that is 37% more organic carbon than conventional tillage method. Krauss *et al.* (2022) reported that the increase in soil organic carbon stocks between reduced tillage (RT) and Conventional tillage (CT) ranged from + 3% to + 44% depending on site and were significantly higher in RT in different locations of the experiment.

The results revealed that the highest organic carbon (2.09 %), available N and P were recorded in minimum tillage and solid row planting. Foxtail millet recorded the highest available N and P, while the highest available K was recorded in proso millet. Seth *et al* (2020) obtained that organic carbon and available N, P and K was higher in zero tillage than conventional tillage. Tillage options did not influence the available potassium in soil after harvest of wheat and rice.

Among the tillage method, the highest available nitrogen content was recorded minimum tillage (301.85 kg ha^{-1}). Among the crop, the highest available nitrogen was observed in foxtail millet (295.54 kg ha^{-1}). The lowest nitrogen was recorded in little millet (277.50 kg ha^{-1}). Among the establishment method, the highest available nitrogen (288.74 kg ha^{-1}) was observed in solid row planting.Minimum tillage recorded the highest available phosphorus content (47.00 kg ha^{-1}). Among the crop, higher available phosphorus content observed in foxtail millet (40.58 kg ha^{-1}) and it was at par with proso millet. The lowest available phosphorus (36.17 kg ha^{-1}) observed in little millet.

The analysed data revealed that crop had significant influence on available potassium content. The higher available potassium was recorded in proso millet (163.17 kg ha^{-1}) and it was on par with foxtail millet. The lowest available potassium was recorded in little millet (155.83 kg ha^{-1}).

Fig 4. Effect of tillage method on organic carbon



SEm (±): 0.060

CD (0.05): 0.390

3.5 CONCLUSION

Tillage and establishment method had a substantial impact on weed density, nutrient uptake, and soil properties and soil health. Conventional tillage, in combination with solid row planting, was most effective in minimizing weed density and dry weight, promoting optimal nutrient uptake by crops, and reducing nutrient losses to weeds. Minimum tillage and solid row planting also contributed to higher organic carbon levels and nutrient availability in the soil. These findings suggest that adopting an appropriate tillage and establishment method can enhance crop yield and soil health, making it a viable strategy for sustainable agricultural practices.

3.6 DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares 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.

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