International Journal of Environment and Climate Change

Volume 13, Issue 11, Page 3177-3191, 2023; Article no.IJECC.108675
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Conservation Agriculture System Impact on Soil Nutrient Status in Eastern Dry Zone of Karnataka, India

Devappa [a++*], Rajashekarappa, K. S. [a#], Mudalagiriyappa [b†], Devaraj, K. [b‡] and Latha, H. S. [b^]

[a] *Department of Soil and Water Engineering, College of Agricultural engineering, University of Agricultural Science, GKVK, Bengaluru-560065, Karnataka, India.*
[b] *AICRP for Dry land Agriculture, University of Agricultural Science, GKVK, Bengaluru-560065, Karnataka, India.*

Authors' contributions

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

Article Information

DOI: 10.9734/IJECC/2023/v13i113488

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/108675

Original Research Article

Received: 07/09/2023
Accepted: 14/11/2023
Published: 15/11/2023

ABSTRACT

Tillage is the physical manipulation of soil into optimum conditions, which enhance the soil health for better crop productivity. A field investigation was carried out to evaluate conservation agriculture effect on soil nutrient conservation and set up in spilt plot design. Zero tillage (M_3) witnessed significantly ($P<0.05$) greater nitrogen availability (288.17, 251.39 and 239.70 kg ha^{-1}), K_2O (229.04, 209.80 and 193.73 kg ha^{-1}) than conventional tillage (M_1) at soil depths 0-7.5, 7.5-15 and 15-30 cm, respectively. In green manuring practices, horse gram (C_3) recorded OC (0.53, 0.51 and 0.47 %),

---

[++] *PG Scholar;*
[#] *Professor (Soil and Water Engineering);*
[†] *Chief Scientist (Agronomy);*
[‡] *Senior Scientist;*
[^] *Senior Scientist (Agronomy);*
**Corresponding author: E-mail: devamtech496@gmail.com;*

available sulphur (23.38, 20.61 and 18.10 mg kg^{-1}) followed by sun hemp. The interaction combination of M_3C_3 recorded highest soil nutrient status. Significantly lowest microbial population were found in M_1, was due to faster decomposition organic matter resulted in unfavourable condition for survival. Overall adopting M_1 alone (1 Ploughing + 2 harrowing + 1 intercultural operation) adversely affect soil health.

Keywords: Conservation tillage; harrowing; green manuring; nitrogen; microbial population; soil health; pigeonpea.

1. INTRODUCTION

The pigeonpea (*Cajanus cajan* L.) is a significant pulse crop with a high protein content. Pigeonpeas are a legume that fix atmospheric nitrogen and, when fully grown, shed a lot of leaves, increasing the organic matter of the soil [1]. Inadequate consumption of pulses could have detrimental effects on human health because they are a rich source of minerals like calcium, phosphorus, iron, and several amino acids that contribute to a balanced diet [2].

Tillage is a crucial and vital field operation in crop production that involves physically modifying the soil to the desired state. In order to create environments favourable for growing crops and seedlings, crop residue management is also crucial. According to R. Derpsch [3], conservation agriculture (CA) keeps an organic soil layer that is either permanent or semi-permanent. Dryland agriculture faces significant challenges in producing crops due to water and nutrient shortages, but there are several alternatives to traditional tillage, including no-tillage, minimum tillage, conservation tillage, and conventional tillage [4]. According to Hu et al. [5] conservation tillage technique is referred as tillage that leaves more than 30 per cent of plant residue remains at the soil surface after planting. According to Bolliger et al. [6] and Christoffoleti et al. [7], it is the most widely utilized soil conservation techniques that involves planting crops straight into the ground without much prior soil preparation. Planting into unprepared soil and not disturbing more than one-third of the soil's surface are both considered no-till or zero-till techniques [3]. In dryland agriculture, killing weeds, preserving soil macro- and micronutrients, and boosting microbial biomass and diversity are the main goals of tillage. Reduced or minimum tillage, as well as zero tillage, have been widely used to achieve conservation tillage goals in rainfed areas due to their numerous environmental, economic, and social benefits over conventional tillage. However, the effectiveness of these techniques depends on the location and the season. According to research by Saha et al. [8], conservation tillage is crucial for maintaining rainfed farms.

According to Derpsch [3], the primary drawbacks of conventional tillage are the excessive soil erosion and organic debris losses that happen during times of intense precipitation, wind, and heat. These losses cause soil macrofauna to die or perform poorly, exposing them to the soil surface and other predators. The physicochemical characteristics of the soil are adversely impacted by this loss of soil biodiversity, which eventually reduces agricultural output. Therefore, biological traits are widely used as indices when characterizing CA soils [9]. According to Tomar et al. [10], when conventional tillage is used, over 25–30% of the energy utilized in agriculture is used for either field preparation or crop establishment. To achieve good crop yields, therefore, excessive soil disturbance through tillage activities is not truly necessary [11]. Thus, according to the chemical, physical, and biological characteristics of soil, soil fertility is the soil ability to deliver sufficient quantities and proportions of key plant nutrients needed for the best growth of specific plants [12]. To ascertain the impact of the conservation agricultural system, a study titled "Effect of Conservation agriculture system on soil nutrient status in eastern dry zone of Karnataka" was conducted. Low-cost in-situ green farming technology aids in increasing soil fertility. Green manure cover crops, including horse gram and sunnhemp, enhance the biological and physicochemical characteristics of the soil by increasing organic matter level in addition to adding nutrients and regulating soil surface temperatures because of their higher surface ground cover [13], controlling soil erosion and conserving soil [14].

2. MATERIALS AND METHODS

In order to evaluate the impact of conservation agriculture on the chemical and biological parameters of alfisols with pigeonpea as a test crop under a rainfed environment during kharif 2021, a field study at All India Coordinated Research Project on Dry Land Agriculture, University of Agricultural Sciences, GKVK, Bengaluru and situated at 13^o 05' N latitude and 77^0 34' E longitude in Karnataka's Eastern Dry zone. The soil at the test location is from the Vijayapura series and is characteristic of the plateau of Bengaluru. The experiment was set up in split plot design with three main plots with various conservation tillage techniques, Conventional tillage M_1: (1 Ploughing + 2 Harrowing + 1 Intercultural operation), Reduced tillage M_2: (1 Harrowing + 1 intercultural operation + pre-emergence herbicide), Zero tillage (M_3): (Pre-emergence herbicide) and sub plots of *in-situ* green manuring practices, C_1: Control, C_2: Sunhemp green manuring, C_3: Horse gram green manuring and replicated three times. Pendimethalin 30 per cent emulsifying concentration @ 1000 g active ingredient per hectare was applied in treatments M_2 and M_3 plots after two days of sowing using Knapsack sprayer fitted with a WFN 78 nozzle and a spray volume of 750 L ha^{-1}. According to the plan and treatments, a tractor-drawn cultivator was used for ploughing, a disc harrow for harrowing and blade hoe for interculture operation. The plots were sown with sunhemp, horse gram and used as *in-situ* green manuring at their 50 % flowering stage. Whereas, line sowing of the main crop sole pigeonpea followed in different conservation tillage treatments using tractor drawn seed drill. The soil samples obtained after harvest from three depths 0-7.5 cm, 7.5 – 15 cm, 15 -30 cm in all plots using soil augur and soil samples before sowing green manure crops were collected at 0-15 cm to obtain initial values of experimental site. As shown in Table 1, standard methods and procedures were used in the laboratory to analyse the soil samples. Using the standard dilution plate count technique and plating on particular nutritional media, the rhizosphere soil samples collected from 0-15 cm deep were examined to count the various populations of soil microorganisms, including total bacteria, fungus, and actinomycetes. The acquired soil samples were well mixed and serially diluted with 1 gram of soil in 100 ml of distilled water. Soil microbial populations were counted and expressed in Colony farming units (CFU). The soil pH was determined in 1:2.5 soil: water suspension using glass electrode pH meter. Electrical conductivity of the clear soil water (1:2.5) suspension was determined using conductivity bridge. 0.5 g of finely powdered sample (0.2 mm) was treated with 10 ml of 1N $K_2Cr_2O_7$ (Potassium dichromate) and 20 ml of concentrated H_2SO_4. After oxidation, excess $K_2Cr_2O_7$ was quantified by back titrating it with standard FAS using ferroin as an indicator. The available nitrogen was estimated by macro Kjeldhal distillation of soil sample following alkaline permanganate method as suggested by Subbaiah and Asija [15]. The available phosphorus was extracted with Bray's extractant (1:10 of soil: extractant). The phosphorus in the extract was determined by stannous chloride reduced molybdophosphoric blue colour method and the intensity of blue colour was read at 660 nm using a spectrophotometer. The available potassium was determined by using flame photometer after extracting the soil with neutral normal ammonium acetate. Exchangeable calcium and magnesium in soil was extracted using neutral normal ammonium acetate. The calcium + magnesium in the extract was determined by adding buffer with EBT indicator titrated against standard EDTA. For calcium using ammonium acetate extract and NaOH with patton's reader indicator titrated against standard EDTA. From the first value calcium content was subtracted to obtain magnesium content in soil and expressed in meq in 100 g soil. Available sulphur in soil was determined using 0.15 % calcium chloride solution and acid seed solution and conditioning agents were added to extractant. The turbidity developed by addition of barium chloride was measured in spectrophotometer with optical density of 420 nm and expressed in ppm.

2.1 Statistical Evaluation of Experimental Data

As stated by Gomez and Gomez [16], the experimental data on the biochemical characteristics of soil were subjected to Fisher's technique of "Analysis of Variance". When the F-test revealed a difference between the treatment means, then an appropriate critical difference (CD) value was calculated. Otherwise, the acronym NS (Non-Significant) was used against CD values. At a probability threshold of 0.05%, all the data were examined, and the findings are presented and discussed.

Table 1. Methodology used in analysis of the soil's initial biochemical characteristics at the experimental location

Sl. No.	Particulars	Initial values	Method adopted
I	**The chemical nature of soil**		
1	Soil pH	5.18	Potentiometric [17]
2	Electrical conductivity	0.05 dS m^{-1}	Conductivity bridge [18]
3	Soil organic carbon	0.46 %	Walkely and Black wet oxidation [18]
4	Soil Organic matter	0.79 %	Walkely and Black wet oxidation [18]
5	Available soil nitrogen	210.52 kg ha^{-1}	Alkaline permanganate method [15]
6	Available soil phosphorus	124.33kg P_2O_5 ha^{-1}	Bray's method [18]
7	Available soil potassium	152.78kg K_2O ha^{-1}	Flame Photometer [18]
8	Exchangeable calcium	3.04 meq 100 g^{-1}	Complexometric titration [18]
9	Exchangeable magnesium	1.85meq 100 g^{-1}	Complexometric titration [18]
	Available sulphur	18.96 mg kg^{-1}	$CaCl_2$ extractant method, Turbidometry [19]
II	**The biological nature of soil**		
1	Bacteria	16 x 10^{6} CFU g soil^{-1}	Carter [20]
2	Fungi	11 x 10^{3} CFU g soil^{-1}	Carter [20]
3	Actinomycetes	5 x 10^{3} CFU g soil^{-1}	Carter [20]

3. RESULTS AND DISCUSSION

3.1 Conservation Agriculture Impact on Available Nitrogen, Phosphorous and Potassium

The information for available nitrogen, phosphorus, and potassium as influenced by various tillage techniques and in-situ green manuring crops at depths of 0-7.5 cm, 7.5- 15 cm, and 15- 30 cm is shown in Table 2. After the pigeonpea crop was harvested, the soil's availability of nitrogen, phosphate, and potassium was significantly impacted by conservation tillage and green manuring techniques.

Among various conservation tillage techniques, zero tillage (M_3) has recorded significantly higher available nitrogen in soil (288.17 , 251.39 and 239.70 kg ha^{-1} at depth 0-7.5 cm, 7.5-15 cm and 15-30 cm, respectively) as compared conventional tillage (M_1) (234.90, 196.58 and 181.92 kg ha^{-1}, respectively).The maximum soil available nitrogen nutrient conservation in M_3 was due to reduced uptake of nutrients by pigeonpea and less loss through immobilization, volatilization, denitrification, surface runoff and leaching. Whereas, lower soil available nutrients in conventional tillage were may be due to enhanced uptake of nutrients caused by lower bulk density, loss of soil nitrogen may have been caused by nitrate leaching. These results support those of [21,22], who found that available soil N, P_2O_5, and K_2O were significantly greater in zero till than in conventional tillage and was comparable to minimum tillage and raised bed methods; In their long-term field experiment, found that No till showed substantial stratification, with the highest concentration of nitrogen in the top soil, but with mouldboard plough tillage, the distribution of nitrogen was uniform throughout the depth [23].

Across manuring techniques, horse gram *in-situ* manuring (C_3) has recorded significantly greater available nitrogen in soil (296.44, 256.95 and 242.55 kg ha^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm, respectively) in comparison to control (C_1) (214.06, 180.65 and 170.51 kg ha^{-1}, respectively). The available nitrogen trend observed in the *in-situ* green manuring crop was in the order of $C_3 > C_2 > C_1$. However, combined effect of tillage and manuring indicated significance difference in nitrogen conservation. The interaction combination of M_3C_3 (Zero tillage + horse gram green manuring) recorded significantly highest available nitrogen status (358.31, 326.88 and 309.50 kg ha^{-1} at 0-7.5, 7.5-15 and 15-30 cm, respectively) and the combination of M_1C_1 (Convention tillage + Control) recorded minimum available nitrogen status (197.52, 166.80 and 153.21 kg ha^{-1} respectively) and also the available nitrogen status of the soil decreased with the depth. The higher available nitrogen status in the surface soil may be due to surface application of fertilizers and *in-situ* green manuring crops with rich in nitrogen content. These results are in accordance with those of [24] who indicated that no till with mulch in wheat had recorded considerably higher total nitrogen, [25] who observed that after six years of conservation agriculture, available nitrogen content increased in zero tillage, and residue retention over conventional tillage and residue removal. Similarly, 10 years' study conducted by [26] concluded that the available nitrogen was more in ZT and residue retained treatment.

Among various conservation tillage adopted, zero tillage (M_3) showed significantly maximum soil available phosphorous status in soil (108.95, 82.73 and 66.82 kg P_2O_5 ha^{-1} at depth 0-7.5 , 7.5-15 and 15-30 cm, respectively) followed by M_2 (98.76, 59.98 and 55.65 kg P_2O_5 ha^{-1}, respectively) and M_1 (81.47, 47.53 and 41.99 kg P_2O_5 ha^{-1}, respectively).The greater soil available phosphorus in M_3 due to lower uptake of nutrients by pigeonpea and less loss through immobilization, volatilization, and leaching. Whereas, lower soil available nitrogen in conventional tillage is because of higher uptake of nutrients due to lower bulk density, loss of soil phosphorus could have been caused by leaching and runoff. These outcomes are consistent with those of [21,27,28] who reported that phosphorous solubilisation was greater in the top soils under zero tillage (ZT) and the increased phosphorous availability under ZT might be due to reduced adsorption of phosphorous to the mineral surfaces and [23] discovered that compared to conventional tillage with flatbed planting, no-tillage with raised bed planting in maize had considerably higher soil organic carbon, available Nitrogen, Phosphorous, and potassium after harvesting crop.

The available phosphorous trend observed among *in-situ* green manuring crops was in the order of $C_3 > C_2 > C_1$. Different tillage techniques and *in-situ* green manuring techniques were shown no significant interaction effect on phosphorous. However, the interaction combination of M_3C_3 (Zero tillage + horse gram manuring) recorded numerically highest available phosphorus status (119.94, 108.33 and 83.91 kg P_2O_5 ha^{-1} at 0-7.5, 7.5-15 and 15-30 cm, respectively) and the combination of M_1C_1 (Convention tillage + Control) recorded lowest available phosphorous status (53.10, 30.12 and 29.03 kg P_2O_5 ha^{-1}, respectively. The addition of organic matter, which releases weak organic acids during decomposition and adds "P" when it breaks down, may also help to dissolve the non-available soil "P" reserve, which could explain the increased phosphorous with these treatments, which is also corroborated by soil pH data and These results support those of [29], who claimed that under sole-crop pulse and intercropping systems, more biological and chemical activity in the rhizosphere may have resulted in higher readily available nutrients. Mineralization of organic phosphorous and a decrease in the fixation of water-soluble P may be the causes of the enhanced availability of phosphorous under residue mulching [30].

There were significant variations in the results on available potassium as influenced by different tillage techniques and green manuring approaches. Zero tillage (M_3) has logged significantly superior available potassium in soil (229.04, 209.80 and 193.73 kg ha^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm, respectively) followed by reduced tillage (M_2) (199.56, 178.15 and 154.56 kg ha^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm respectively) and conventional tillage (M_1) (187.59 ,159.50 and 142.38 kg ha^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm, respectively). The reduced nutrient uptake by pigeonpea and a decrease in loss due to immobilization, volatilization, increased soil organic matter under conservation tillage practice contributed to the higher available pool of soil potassium in the top soils [31] and leaching may be the causes of the increased soil accessible potassium in zero tillage. In contrast, reduced soil nutrients M_1 may be the result of higher nutrient uptake caused by decreased bulk density. These results are in acceptance with the findings of [21-23,32], who found that zero tillage had higher levels of solution potassium than conventional tillage, which declined with depth and as stated by [33], zero tillage preserves and improves potassium availability close to the soil surface, where crop roots flourish.

Among different *in-situ* green manuring practices, the available potassium trend observed was in the order of $C_3 > C_2 > C_1$. The interaction between various tillage techniques and green manuring techniques had no discernible impact on available potassium. However, the interaction combination of M_3C_3 reported quantitatively highest available potassium status (250.33, 239.91 and 220.33 kg ha^{-1}, respectively) and the combination M_1C_1 recorded least available potassium status (158.28, 132.00 and 124.19 kg ha^{-1}, respectively). The highest level of potassium availability in the surface soil may be caused by

Table 2. Effects of conservation agriculture on the soil's readily available nitrogen, phosphate, and potassium under a pigeonpea cropping system

Treatments	**Nitrogen (kg ha^{-1})**			**Phosphorus (kg P_2O_5 ha^{-1})**			**Potassium (kg K_2O ha^{-1})**		
	0-7.5 cm	**7.5-15 cm**	**15-30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15-30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15-30 cm**
Tillage practice									
M_1: Conventional tillage	234.90	196.58	181.92	81.47	47.53	41.99	187.59	159.50	142.38
M_2: Reduced tillage	247.49	208.19	199.34	98.76	59.98	55.65	199.56	178.15	154.56
M_3: Zero tillage	288.17	251.39	239.70	108.95	82.73	66.82	229.04	209.80	193.73
S. Em. ±	**7.07**	**6.34**	**4.76**	**2.80**	**3.23**	**1.82**	**7.34**	**4.87**	**3.99**
CD (p=0.05)	**27.78**	**24.88**	**18.71**	**10.98**	**12.69**	**7.14**	**28.81**	**19.11**	**15.66**
***In-situ* green manuring crops**									
C_1: Control	214.06	180.65	170.51	76.84	41.44	38.97	170.01	147.85	136.17
C_2: Sunhemp	260.05	218.56	207.90	103.96	68.15	58.97	218.59	193.32	171.39
C_3: Horse gram	296.44	256.95	242.55	108.38	80.65	66.52	227.59	206.28	183.10
S. Em. ±	**6.71**	**4.00**	**4.14**	**2.57**	**2.99**	**1.67**	**4.97**	**4.66**	**3.54**
CD (p=0.05)	**20.68**	**12.33**	**12.76**	**7.92**	**9.21**	**5.15**	**15.32**	**14.35**	**10.91**
Interaction									
M_1C_1	197.52	166.80	153.21	53.10	30.12	29.03	158.28	132.00	124.19
M_1C_2	247.98	207.98	194.64	93.26	50.34	44.80	195.96	159.46	147.17
M_1C_3	259.20	214.98	197.92	98.06	62.13	52.15	208.52	187.04	155.78
M_2C_1	210.09	177.08	172.22	86.74	44.93	42.78	159.36	152.76	131.75
M_2C_2	260.57	218.49	205.55	102.38	63.53	60.66	215.40	189.79	158.73
M_2C_3	271.82	229.00	220.24	107.15	71.48	63.50	223.92	191.88	173.19
M_3C_1	234.58	198.08	186.11	90.67	49.28	45.11	192.39	158.78	152.57
M_3C_2	271.60	229.19	223.51	116.25	90.56	71.45	244.40	230.70	208.27
M_3C_3	358.31	326.88	309.50	119.94	108.33	83.91	250.33	239.91	220.33
S. Em. ±	**11.62**	**6.93**	**7.17**	**4.45**	**5.18**	**2.90**	**8.61**	**8.07**	**6.13**
CD (p=0.05)	**35.81**	**21.36**	**22.09**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

the *In-situ* green manuring of potassium-rich crops and fertilizer surface applications. These views are in line with those of; [32] and [34] who stated that mulching with maize residue has recorded considerably maximum available Nitrogen, Phosphorous and potassium in post-harvest soil samples as associated to control.

3.2 Conservation Agriculture Impact on pH and Electrical Conductivity of Soil

Table 3 displays data on electrical conductivity and soil pH as influenced by different tillage methods and green manuring techniques at depths of 0-7.5, 7.5- 15, and 15- 30 cm. The availability of critical nutrients to plants and the microbial population within the soil are influenced by the pH of the soil, which is crucial for plant growth. None of the treatment interactions of tillage and manuring revealed a significant variation in the pH of the soil. However, in zero tillage (M_3) significantly lower pH (4.64, 4.92 and 5.05 at 0-7.50, 7.5- 15 and 15- 30 cm, respectively) was noticed and followed by reduced tillage (M_2) (4.70, 4.96 and 5.13, respectively). The pH value across tillage practices ranged from 4.64 at depth 7.5 cm to 5.24 at 30 cm depth in M_3 and M_1, respectively. The reason why no-till systems have lower soil pH than M1 is because there is more organic matter accumulating in the top few centimetres of the soil under zero tillage [35], which raises the concentration of electrolytes and lowers the pH [36] and These are supported by Busari et al. [37], that practicing of zero tillage in maize has considerably lowered soil pH when contrasted with conventional tillage and [38] who reported that in silty-loam soil, pH was unaltered by soil tillage for seven years, but increased with soil depth.

The pH trend among the crops used for in-situ green manuring was C_3 followed by C_2 (Sunhemp) and C_1. Additionally indicated that, there was no significant pH difference in interaction between the tillage system and in-situ green manuring technique. The addition of organic mulches and green manuring may have assisted in preserving soil organic matter, which raises soil pH. When the organic matter supplied in these treatments decomposes, weak acids are released, which may dilute acidity and raise the pH in acidic soils and which are supported by Kumar et al. [39].

The electrical conductivity of the soil among different conservation tillage, *in-situ* green manuring practices and their interaction effect was found non-significant difference at all depths. Among different conservation tillage practices M_3 has recorded significantly higher EC (0.09, 0.07 and 0.05 dSm^{-1} at 0-7.50, 7.5- 15 and 15- 30 cm, respectively) followed by reduced tillage M_2. Among *in-situ* green manuring crops, C_3 recorded numerically highest EC 0.09 dSm^{-1} at 0-7.50 cm depth. The maximum electrical conductivity in M_3 and horse gram *in-situ* green manuring (C_3) might be because of presence more organic matter. These findings agree with those of [40] and [41], who found that mouldboard tillage on vertisols reduced soil electrical conductivity compared to no tillage.

3.3 Conservation Agriculture Impact on Organic Carbon and Organic Matter of Soil

Table 3 shows the information on soil organic carbon (OC) and organic matter (OM) as affected by various tillage techniques and in-situ green manuring crops at depths of 0-7.50, 7.5- 15 and 15- 30 cm. Significant differences were identified in the data on ‘OC’ as affected by various conservation tillage and in-situ green manuring techniques. Between conservation tillage practices, M_3 has revealed significantly greater OC (%) in soil (0.54, 0.53 and 0.50% at depth 0-7.5, 7.5-15 and 15-30 cm, respectively) in comparison to M_1 (0.47, 0.44 and 0.40%, respectively). A minimum of OC was observed in M_1 due to repeated tillage associated with maximum soil disturbance, which accelerated the oxidation process in soil and decreased the status of organic carbon in soil. No ploughing operations and no disturbances as in the case of zero tillage led to the accumulation of more organic waste with a slower rate of decomposition. These results agree with the findings of [24] who found that no till with mulch in wheat has recorded considerably higher soil organic carbon than conventional tillage, [42,22,23] who observed that no-till with raised bed planting in maize has significantly greater soil organic carbon than the conventional tillage with flatbed planting; [43] and [44].

When compared to control (0.47, 0.45, and 0.42%), C3's in-situ green manuring recorded the significantly greater OC (0.53, 0.51, and 0.47% at depths 0-7.5, 7.5-15, and 15-30 cm, respectively) and horse gram *in-situ* green manuring (C_3) was on par with the *in-situ* green manuring of sunhemp (C_2) at all the depths. With regard to soil organic carbon, the interaction impact between conservation tillage and green manuring techniques was observed, however the difference was not statistically significant. Whereas, numerically highest OC was detected in the interaction combination M_3C_3 (0.57, 0.56 and 0.53 % at depth 0-7.5, 7.5-15 and 15-30 cm, respectively). In-situ green manuring resulted in high microbial biomass generation as well as high rhizo deposits of carbonaceous material through root exudates, which may have contributed to the horse gram *in-situ* green manuring's higher organic carbon content than the control. These findings are consistent with Singh et al.'s [12] research, which showed that zero tillage with residue maintenance in maize produced a crop with a considerably higher organic carbon content than zero tillage without residue maintenance.

It was discovered that the data on organic matter (OM) as affected by various conservation tillage and green manuring strategies was significant. Across the tillage and green manuring practices, organic carbon trend observed was in the order of $M_3 > M_2 > M_1$ and $C_3 > C_2 > C_1$. The lower OM in M_1 may be due to excessive aeration which caused faster decomposition of organic matter in the soil and on the surface. The greater OM in M3 is due to no disturbance of soil activated the soil microbiology resulted in the faster build-up of soil organic matter content and These views are supported by those of [42], and (Kashif et al., 2006), who found that minimum tillage yielded significantly greater OM than deep tillage and conventional tillage.

Application of horse gram green manuring (C_3) has recorded the significantly highest OM (0.92, 0.88 and 0.82% at depth 0-7.5, 7.5-15 and 15-30 cm, respectively) followed by C_2 and C_1. The horse gram *in-situ* green manuring (C_3) was on

Table 3. Conservation agriculture impact on pH, EC, OC and OM variation within the soil

Treatments	**pH**			**EC (dS m^{-1})**			**OC %**			**OM %**		
	0-7.5 cm	**7.5-15 cm**	**15 - 30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15 - 30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15 - 30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15 - 30 cm**
Tillage practice												
M_1: Conventional tillage	4.77	5.04	5.24	0.07	0.05	0.03	0.47	0.44	0.40	0.82	0.76	0.70
M_2: Reduced tillage	4.70	4.96	5.13	0.08	0.06	0.04	0.50	0.47	0.44	0.86	0.82	0.76
M_3: Zero tillage	4.64	4.92	5.05	0.09	0.07	0.05	0.54	0.53	0.50	0.93	0.91	0.86
S. Em. ±	**0.05**	**0.08**	**0.10**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.03**	**0.03**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.05**	**0.06**	**0.07**	**0.08**	**0.10**	**0.12**
Green manuring practices												
C_1: Control	4.76	5.03	5.21	0.06	0.04	0.03	0.47	0.45	0.42	0.81	0.77	0.72
C_2: Sunhemp	4.71	4.96	5.14	0.08	0.06	0.05	0.51	0.48	0.45	0.88	0.83	0.78
C_3: Horse gram	4.64	4.93	5.06	0.09	0.07	0.05	0.53	0.51	0.47	0.92	0.88	0.82
S. Em. ±	**0.06**	**0.05**	**0.07**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.03**	**0.03**	**0.04**	**0.05**	**0.05**	**0.06**
Interaction												
M_1C_1	4.79	5.15	5.37	0.06	0.04	0.03	0.45	0.41	0.38	0.78	0.72	0.65
M_1C_2	4.77	5.01	5.24	0.07	0.05	0.03	0.48	0.44	0.40	0.82	0.76	0.69
M_1C_3	4.75	4.96	5.11	0.08	0.06	0.04	0.49	0.47	0.43	0.85	0.81	0.74
M_2C_1	4.77	5.01	5.19	0.07	0.05	0.03	0.46	0.43	0.39	0.79	0.74	0.68
M2C_2	4.72	4.95	5.12	0.08	0.06	0.05	0.51	0.49	0.46	0.87	0.84	0.79
M_2C_3	4.62	4.93	5.08	0.08	0.06	0.05	0.53	0.50	0.47	0.91	0.87	0.80
M_3C_1	4.72	4.94	5.08	0.07	0.05	0.04	0.50	0.49	0.48	0.85	0.85	0.82
M_3C_2	4.63	4.92	5.06	0.09	0.07	0.05	0.54	0.53	0.49	0.94	0.91	0.85
M_3C_3	4.57	4.90	5.00	0.10	0.08	0.06	0.57	0.56	0.53	0.98	0.97	0.91
S. Em. ±	**0.11**	**0.09**	**0.12**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.02**	**0.03**	**0.03**	**0.04**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

par with the *in-situ* green manuring of C_2 at all the depths. The highest organic matter in C_3 may be attributed to higher ground cover resulted in the minimum loss of organic matter by the runoff volume and these study outcomes are in parallel with those of Yan and Li [45] who asserted that incorporation of legumes to the soil enhanced the organic matter than control (without green manuring).

3.4 Conservation Agriculture Impact on Exchangeable Calcium, Magnesium and Available Sulphur in Soil

Table 4 provides information on the status of exchangeable calcium, magnesium, and sulphur as modified by conservation tillage and green manuring techniques at depths 0–7.50, 7.5–15, and 15–30 cm. After crop harvest, the soil's exchangeable calcium and magnesium status has significantly varied due to various conservation tillage techniques and in-situ green manuring crops. In conservation tillage techniques, M_3 has recorded significantly highest exchangeable calcium and magnesium status in soil (1.58, 1.50, 1.44 meq 100g^{-1} and 0.88, 0.77 and 0.68 meq 100g^{-1}, respectively at depth 0-7.5, 7.5-15 and 15-30 cm, respectively) in comparison to M_1 (1.42, 1.35, 1.28 meq 100g^{-1} and 0.69, 0.63, 0.49 meq 100g^{-1}, respectively) and also which was on par with M_2 tillage (1.49, 1.41 and 1.35 meq 100g^{-1} 0-7.5, 7.5-15 and 15-30 cm, respectively) with respect to exchangeable calcium at all depths. The higher soil available nutrients in M_3 may be due to lower uptake, higher organic matter status in soil and These results are supported by Edwards et al. [46], who found that, zero tillage with higher extractable calcium concentrations on an Ultisol than conventional tillage, which they theorized could be due to the higher soil organic matter content of zero tillage; [47], who discovered that tillage practices affected the concentration of exchangeable Calcium, Magnesium, and Sulphur.

Among different in-situ green manuring practices, C_3 noticed significantly higher exchangeable calcium and magnesium status in soil (1.54, 1.47, 1.43 meq 100g^{-1} and 0.87, 0.75 and 0.67 meq 100g^{-1}, respectively at depth 0-7.5 , 7.5-15 and 15-30 cm respectively) as compared to control (C_1) (1.42, 1.33, 1.24 meq 100g^{-1} and 0.63 , 0.61, 0.43 meq 100g^{-1} respectively).Whereas, horse gram *in-situ* manuring (C_3) has on par results with the sunhemp in-situ green manuring with respect to the exchangeable calcium and magnesium. There were no significant variations in the soil's exchangeable calcium and magnesium found as a result of the interaction between tillage and manuring. However, the combination M_3C_3 recorded numerically highest exchangeable calcium and magnesium (1.64, 1.59, 1.54 meq 100g^{-1} and 0.98, 0.86 and 0.78 meq 100g^{-1}, respectively) and the combination of M_1C_1 recorded lowest exchangeable calcium and magnesium (1.34, 1.29, 1.17 meq 100g^{-1} and 0.61, 0.57 and 0.40 meq 100g^{-1}, respectively). These findings align with those of [28].

Zero tillage (M_3), the most effective conservation tillage technique, recorded the most significant levels of soil sulphur (23.45, 21.06, and 18.28 mg kg-1 at depths 0-7.5, 7.5-15, and 15-30 cm, respectively), followed by M_2 and M_1. The maximum available sulphur in M_3 is due to witness of higher organic matter retained and lowest available sulphur in M_1 may be soil exposed solar radiation caused degradation of organic matter content resulted in loss of nutrient status of soil [47].

Among different *in-situ* green manuring practices, horse gram *in-situ* manuring (C_3) showed significantly greater available sulphur status in the soil (23.38, 20.61 and 18.10 mg kg^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm respectively) as compared to control (C_1) (15.29, 13.95 and 12.57 mg kg^{-1} at depth 0-7.5, 7.5-15 and 15-30 cm, respectively). there was no significance variation in sulphur was noticed across various conservation tillage and manuring combination. However, the interaction combination of M_3C_3 recorded numerically maximum available sulphur (27.46, 25.77 and 21.79 mg kg^{-1} at 0-7.5, 7.5-15 and 15-30 cm respectively) and the combination of M_1C_1 recorded lowest available sulphur (13.74, 12.53 and 10.86 mg kg^{-1} respectively) and also the available sulphur in soil decreased with the depth may be because of slower decomposition of surface applied residue, retained more nutrient and prevented rapid leaching of nutrients through soil profile. The higher available sulphur may be due to additional application of organic residue enriched the net sulphur immobilization in the soil.

3.5 Tillage and Manuring Impact on Soil Microbial Population

Table 5 provides information on bacteria, fungus, and actinomycetes in relation to tillage techniques and in-situ green manuring crops at a depth of 0 to 15 cm. Following the harvest of the pigeonpea crop, conservation tillage techniques and in-situ green manuring crops have significantly changed the microbial population in the soil. Zero tillage (M_3) has recorded significantly maximum population of bacteria, fungi and actinomycete in soil (21.03×10^6, 18.26×10^3 and 8.38×10^3 CFU g^{-1} of soil, respectively) in comparison to M_1 (14.42×10^6, 11.47×10^3 and 5.71×10^3 CFU g^{-1} of soil, respectively). The microbial population observed among tillage practices was in the order of $M_3 > M_2 > M_1$. The maximum microbial population in M_3 were due to no ploughing, no disturbance of soil, better soil moisture content and increased availability of food through organic matter made better environment for the survival of microbes. Whereas, lower soil microbial population under M_1 was due to excessive ploughing operations, sequent intercultural operations caused greater soil disturbance, lowest soil moisture and faster decomposition organic matter resulted in the unfavourable condition for their survival. These results are consistent with those of [48], who found that reduced tillage boosted the microbial population when compared to conventional tillage; [44] who reported highest bacteria, fungi and actinomycetes in zero tillage followed by reduced and convention tillage. Rosegrant et al., [49] who reported higher number of microorganisms and earth worm biomass in conservation tillage over conventional tillage; (Murugandam et al., 2009) who revealed that no-till practices improve soil microbial biomass carbon as compared to chisel plough and mould board plough; [11] who observed that the minimum tillage in Alfisols resulted in significantly more microbial biomass carbon in comparison to conventional and reduced tillage.

Table 4. Conservation agriculture influence on exchangeable calcium, magnesium and available sulphur of soil

Treatments	**Ca (meq 100 g^{-1})**			**Mg (meq 100 g^{-1})**			**Sulphur (mg kg^{-1})**		
	0-7.5 cm	**7.5-15 cm**	**15-30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15-30 cm**	**0-7.5 cm**	**7.5-15 cm**	**15-30 cm**
Tillage practice									
M_1: Conventional tillage	1.42	1.35	1.28	0.69	0.63	0.49	16.61	14.67	13.12
M_2: Reduced tillage	1.49	1.41	1.35	0.77	0.67	0.56	20.27	17.39	15.99
M_3: Zero tillage	1.58	1.50	1.44	0.88	0.77	0.68	23.45	21.06	18.28
S. Em. ±	**0.03**	**0.03**	**0.03**	**0.02**	**0.02**	**0.02**	**0.63**	**0.79**	**0.59**
CD (p=0.05)	**0.12**	**0.11**	**0.12**	**0.10**	**0.08**	**0.06**	**2.48**	**3.09**	**2.31**
Green manuring practices									
C_1: Control	1.42	1.33	1.24	0.63	0.61	0.43	15.29	13.95	12.57
C_2: Sunhemp	1.52	1.44	1.40	0.84	0.71	0.64	21.65	18.55	16.73
C_3: Horse gram	1.54	1.47	1.43	0.87	0.75	0.67	23.38	20.61	18.10
S. Em. ±	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.54**	**0.76**	**0.42**
CD (p=0.05)	**0.08**	**0.08**	**0.07**	**0.07**	**0.05**	**0.05**	**1.65**	**2.33**	**1.30**
Interaction									
M_1C_1	1.34	1.29	1.17	0.61	0.57	0.40	13.74	12.53	10.86
M_1C_2	1.45	1.38	1.32	0.72	0.66	0.52	17.14	15.20	13.96
M_1C_3	1.47	1.38	1.35	0.75	0.67	0.55	18.93	16.26	14.54
M_2C_1	1.42	1.35	1.26	0.59	0.60	0.37	14.66	14.51	13.30
M2C_2	1.51	1.42	1.37	0.84	0.69	0.63	22.40	17.85	16.72
M_2C_3	1.53	1.45	1.41	0.88	0.71	0.67	23.74	19.80	17.95
M_3C_1	1.50	1.37	1.29	0.70	0.65	0.51	17.47	14.80	13.54
M_3C_2	1.60	1.54	1.50	0.96	0.79	0.76	25.41	22.59	19.51
M_3C_3	1.64	1.59	1.54	0.98	0.86	0.78	27.46	25.77	21.79
S. Em. ±	**0.05**	**0.04**	**0.04**	**0.04**	**0.03**	**0.03**	**0.93**	**1.31**	**0.73**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 5. Conservation agriculture system impact on microbial population at 15 cm soil depth

Treatments	**Bacteria** **No. × 10^6 CFU g^{-1} of soil**	**Fungi** **No. × 10^3 CFU g^{-1} of soil**	**Actinomycetes** **No. × 10^3 CFU g^{-1} of soil**
Tillage practice			
M_1: Conventional tillage	14.42	11.47	5.71
M_2: Reduced tillage	19.78	14.25	6.86
M_3: Zero tillage	21.03	18.26	8.38
S. Em. ±	**0.51**	**0.85**	**0.39**
CD (p=0.05)	**2.00**	**3.34**	**1.52**
***In-situ* green manuring practices**			
C_1: Control	12.38	9.03	3.87
C_2: Sunhemp	20.13	16.47	8.12
C_3: Horse gram	22.71	18.48	8.95
S. Em. ±	**0.37**	**0.56**	**0.35**
CD (p=0.05)	**1.14**	**1.73**	**1.08**
Interaction			
M_1C_1	9.75	7.05	2.72
M_1C_2	15.88	13.51	6.19
M_1C_3	17.63	13.87	8.23
M_2C_1	13.28	7.59	3.51
$M2C_2$	21.70	17.01	8.51
M_2C_3	24.35	18.14	8.55
M_3C_1	14.11	12.46	5.38
M_3C_2	22.82	18.89	9.66
M_3C_3	26.16	23.42	10.09
S. Em. ±	**0.64**	**0.97**	**0.60**
CD (p=0.05)	**NS**	**NS**	**NS**

Among the various in-situ green manuring techniques, horse gram (C_3) has reported significantly greater population of bacteria, fungi and actinomycetes status in soil (22.71×10^6, 18.48×10^3 and 8.95×10^3 CFU g^{-1} of soil, respectively) as compared to control (C_1) (12.38×10^6, 9.03×10^3 and 3.87×10^3 g^{-1} of soil, respectively). The combined impact of tillage and green manuring on all three types of microorganisms population means shown statistically non-significant differences. However, the interaction combination of M_3C_3 recorded numerically highest population of bacteria, fungi and actinomycetes (26.16×10^6, 23.42×10^3 and 10.09×10^3 CFU g^{-1} of soil, respectively) and the combination of M_1C_1 recorded lowest population of bacteria, fungi and actinomycetes (9.75×10^6, 7.05×10^3 and 2.72×10^3 CFU g^{-1} of soil, respectively). The highest microbial population of bacteria, fungi, and actinomycetes was found in horse gram *in-situ* green manuring, which may be related to the slower rate of organic residue decomposition that resulted in continuous food availability and better soil moisture conservation that kept the microclimate of lower soil temperature and facilitated their quick multiplication. These outcomes are consistent with the findings of [50]; (Tilak, 2004); [51]; [52] and [53-58].

4. CONCLUSION

The Conventional tillage M_1: (1 Ploughing + 2 Harrowing + 1 intercultural operation) created excessive soil pulverization and which caused loss of soil nutrients through mobilization, volatilization, and leaching. Loss of organic matter content in conventional tillage due to faster decomposition either kill or disturb the functions of soil macrofauna. Thus, practicing zero tillage (M_3): (Pre-emergence herbicide) conserve the plants essential nutrients such as nitrogen, phosphorous, sulphur, potassium, calcium, magnesium and improved the soil organic carbon content which is direct measure of soil fertility. Zero tillage practice with horse gram green manuring (M_3C_3) witnessed the better bio-chemical properties of soil as compared others. In long-term, following zero tillage alone can restrict the crop yield because of weed competition and soil compaction. Therefore, practicing reduced tillage $M_{2:}$ (1 Harrowing + 1 intercultural operation + pre-emergence herbicide) can overcome the constraints of conventional and zero tillage with respect to total soil health.

ACKNOWLEDGMENT

Authors sincerely acknowledge the acknowledge the support provided by the All India Coordinated Research Project on Dryland Agriculture, University of Agriculture Science, GKVK, Bengaluru for this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Nanjappa HV, Ramachandrappa BK. Effect of tillage and nutrient management practices on weed dynamics and yield of fingermillet (*Eleusine coracana* L.) under rainfed pigeonpea (*Cajanus cajan* L.) fingermillet system in Alfisols of Southern India. African Journal of Agricultural Research. 2013;8(21):2470-5.
2. Kalaiselvi A. Grain drain: Food crisis in India, Kisan world. 2008;35(4): 22- 23.
3. Derpsch R. Conservation tillage, no-tillage and related technologies. InConservation agriculture: environment, farmers experiences, innovations, socio-economy, policy. Dordrecht: Springer Netherlands. 2003;181-190.
4. Lal R. Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. Soil and Tillage Research. 1997;43(1-2):81-107.
5. Hu X, Liu J, Liang A, Li L, Yao Q, Yu Z, Li Y, Jin J, Liu X, Wang G. Conventional and conservation tillage practices affect soil microbial co-occurrence patterns and are associated with crop yields. Agriculture, Ecosystems & Environment. 2021;319: 107534.
6. Bolliger A, Magid J, Amado JC, Neto FS, dos Santos Ribeiro MD, Calegari A, Ralisch R, de Neergaard A. Taking stock of the Brazilian “zero-till revolution”: A review of landmark research and farmers' practice. Advances in Agronomy. 2006;91:47-110.
7. Christoffoleti PJ, De Carvalho SJ, López-Ovejero RF, Nicolai M, Hidalgo E, Da Silva JE. Conservation of natural resources in Brazilian agriculture: Implications on weed biology and management. Crop Protection. 2007;26(3):383-9.

8. Saha S, Chakraborty D, Sharma AR, Tomoar RK, Bhadraray S, Sen U, Behera UK, Purakayastha TJ, Garg RN, Kalra N. Effect of tillage and residue management on soil physical properties and crop productivity in maize (*Zea mays*)–Indian mustard (*Brassica juncea*) system. Indian Journal of Agricultural Sciences. 2010;80(8):679-85.
9. Jayaraman S, Dang YP, Naorem A, Page KL, Dalal RC. Conservation agriculture as a system to enhance ecosystem services. Agriculture. 2021;11(8):718.
10. Tomar RK, Garg RN, Gupta VK. Optimum tillage and resource conservation technologies for cropping systems. Indian Farming. 2006; 56:27-32.
11. Rajendra P, Kumar D, Shivay YS. Strategies for sustained soil fertility. Indian Farming. 2006; 56:4-8.
12. Singh V, Srivastava A, Singh RK, Savita US. Effect of tillage practices and residue management on soil quality and crop yield under maize (*Zea mays*)—Based cropping system in Mollisol. Indian Journal of Agricultural Sciences. 2011;81(11):1019.
13. Pasha MM. Effect of Organic Mulches and Green Manuring on Soil Moisture Conservation, Infiltration, Growth and Yield of Maize *(Zea Mays L.)* in Alfisols (Doctoral dissertation, University of Agricultural Sciences, GKVK); 2018.
14. Buckles D, Triomphe B, Sain G. Cover crops in hillside agriculture: farmer innovation with Mucuna. Idrc; 1998.
15. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Current Science. 1956 Aug 1;25(8):259-60.
16. Gomez, KA, Gomez AA. Stastical procedure for agriculltural research. John Wileyand sons; New Delhi. 1984;680.
17. Piper CS. Soil and Plant Analysis' scientific publishers: New York; 1966.
18. Jackson ML. Soil chemical analysis', Prentice Hall of India Pvt. Ltd., New Delhi. 1973; 498.
19. Black CA, 'Method of Soil Analysis part II Agronomy monograph No, 9, American Society of Agronomy, Madison, Wisconsin, p.148.
20. Carter MR. Ninhydrin-reactive N released by the fumigation-extraction method as a measure of microbial biomass under field conditions. Soil Biology and Biochemistry. 1991 ;23(2):139-43.
21. Mina BL, Saha S, Kumar N, Srivastva AK, Gupta HS. Changes in soil nutrient content and enzymatic activity under conventional and zero-tillage practices in an Indian sandy clay loam soil. Nutrient Cycling in Agroecosystems. 2008;82(3):273-81.
22. Sharma MP, Gupta S, Sharma SK, Vyas AK. Effect of tillage and crop sequences on arbuscular mycorrhizal symbiosis and soil enzyme activities in soybean (*Glycine max*) rhizosphere. Indian Journal of Agricultural Sciences. 2012; 82 (1): 25-30.
23. Yadav GS, Datta M, Babu S, Das A, Bhowmik SN, Ranebennur H, Debnath C, Saha P. Effect of tillage and crop-establishment techniques on productivity, profitability and soil health under maize (Zea mays)-maize-field pea (*Pisum sativum*) cropping system. Indian Journal of Agronomy. 2015;60(3):360-4.
24. Jin K, Sleutel S, Buchan D, De Neve S, Cai DX, Gabriels D, Jin JY. Changes of soil enzyme activities under different tillage practices in the Chinese Loess Plateau. Soil and Tillage Research. 2009;104(1):115-20.
25. Nandan R, Singh V, Singh SS, Kumar V, Hazra KK, Nath CP, Poonia S, Malik RK, Bhattacharyya R, McDonald A. Impact of conservation tillage in rice–based cropping systems on soil aggregation, carbon pools and nutrients. Geoderma. 2019; 340:104-14.
26. Li Y, Li Z, Chang SX, Cui S, Jagadamma S, Zhang Q, Cai Y. Residue retention promotes soil carbon accumulation in minimum tillage systems: Implications for conservation agriculture. Science of the Total Environment. 2020;740:140147.
27. Sharma P, Abrol V, Shankar GR. Effect of tillage and mulching management on the crop productivity and soil properties in maize-wheat rotation. Indian Journal of Crop Science. 2008;3(1):141-4.
28. Mohanty A, Mishra KN, Roul PK, Dash SN, Panigrahi KK. Effects of conservation agriculture production system (CAPS) on soil organic carbon, base exchange characteristics and nutrient distribution in a tropical rainfed agro-ecosystem. Int. J. Plant Anim. Environ. Sci. 2015; 5:310-4.
29. Inal A, Gunes A, Zhang F, Cakmak I. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant physiology and biochemistry. 2007;45(5):350-6.

30. Kuotsu K, Das A, Lal R, Munda GC, Ghosh PK, Ngachan SV. Land forming and tillage effects on soil properties and productivity of rainfed groundnut (*Arachis hypogaea* L.)–rapeseed (*Brassica campestris* L.) cropping system in northeastern India. Soil and Tillage Research. 2014; 142:15-24.
31. Thomas GA, Dalal RC, Standley J. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil and Tillage Research. 2007;94(2):295-304.
32. Du Preez CC, Steyn JT, Kotze E. Long-term effects of wheat residue management on some fertility indicators of a semi-arid Plinthosol. Soil and tillage Research. 2001;63(1-2):25-33.
33. Franzluebbers AJ, Hons FM, Zuberer DA. Tillage-induced seasonal changes in soil physical properties affecting soil CO2 evolution under intensive cropping. Soil and Tillage Research. 1995;34(1):41-60.
34. Mallareddy. Comparative efficacy of different moisture conservation practices on productivity and soil moisture dynamics in finger millet + pigeonpea intercropping system. M. Sc (Agri.) Thesis, University of Agricultural Sciences, Bengaluru, Karnataka, India. 2014.
35. Rhoton FE. Influence of time on soil response to no-till practices. Soil Science Society of America Journal. 2000;64(2):700-9.
36. Rahman MM, Gathala MK, Timsina J, Islam MS, Hossain MI, Harun-Ar-Rashid M, Ghosh AK, Krupnik TJ, Tiwari TP, McDonald A. Conservation agriculture-based tillage and crop establishment options can maintain farmers’ yields and increase profits in South Asia's rice–maize systems: Evidence from Bangladesh. Field Crops Research. 2015 Feb 15; 172:85-98.
37. Busari MA, Salako FK. Effect of tillage, poultry manure and NPK fertilizer on soil chemical properties and maize yield on an Alfisol at Abeokuta, south-western Nigeria. Nigerian Journal of Soil Science. 2013;23(2):206-18.
38. Neugschwandtner RW, Liebhard P, Kaul HP, Wagentristl H. Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. Plant, Soil and Environment. 2014;60(2):57-62.
39. Kumar R, Sood S, Sharma S, Kasana RC, Pathania VL, Singh B, Singh RD. Effect of plant spacing and organic mulch on growth, yield and quality of natural sweetener plant Stevia and soil fertility in western Himalayas. International Journal of Plant Production. 2014;8(3):311-34.
40. Patil PV, Chalwade PB, Solanke AS, Kulkarni VK. Effect of fly ash and FYM on physico-chemical properties of Vertisols. Journal of Soils and Crops. 2003;13(1):59-64.
41. Roldan A, Salinas-Garcia JR, Alguacil MM, Caravaca F. Soil sustainability indicators following conservation tillage practices under subtropical maize and bean crops. Soil and Tillage Research. 2007;93(2):273-82.
42. Bilalis DJ, Karkanis A, Papastylianou P, Patsiali S, Athanasopoulou M, Barla G, Kakabouki I. Response of Organic Linseed (*'Linum usitatissimum'* L.) to the Combination of Tillage Systems, (Minimum, Conventional and No-Tillage) and Fertilization Practices: Seed and Oil Yield Production. Australian Journal of Crop Science. 2010;4(9): 700-5.
43. Singh KB, Jalota SK, Gupta RK. Soil water balance and response of spring maize (Zea mays) to mulching and differential irrigation in Punjab. Indian Journal of Agronomy. 2015;60(2):279-84.
44. Hatti V, Ramachandrappa BK, Sathishand A, Thimmegowda MN. Soil properties and productivity of rainfed finger millet under conservation tillage and nutrient management in Eastern dry zone of Karnataka. Journal of Environmental Biology. 2018;39(5):612-24.
45. Yan XC, Li DM. Effect of planting green manure legumes on purple dry land soil. Journal of Soil Science. 1985;16:112-5.
46. Edwards JH, Wood CW, Thurlow DL, Ruf ME. Tillage and crop rotation effects on fertility status of a Hapludult soil. Soil Science Society of America Journal. 1992;56(5):1577-82.
47. Douglas-Mankin KR, Daggupati P, Sheshukov AY, Barnes PL. Paying for sediment: Field-scale conservation practice targeting, funding, and assessment using the Soil and Water Assessment Tool. Journal of Soil and Water Conservation. 2013;68(1):41-51.
48. Xia GM, Lu XC. Microbial activity in paddy soil of reduced tillage and located area broadcast sowing. Soil and Fertilizers Abstracts.1992;66-229.

49. Rosegrant MW, Cai X, Cline SA. World water and food to 2025: Dealing with scarcity. Intl Food Policy Res Inst; 2002.
50. Schenck S. Soil Incorporation of Covercrop Biomass: Effects on Soil Microorganisms and Nitrogen Levels. Hawaii Agriculture Research Center Diversified Crops Report. 2003 Nov(23).
51. Krishna KR. Agroecosystems of South India: Nutrient dynamics, ecology and productivity. Universal-Publishers; 2010.
52. Govaerts B, Mezzalama M, Unno Y, Sayre KD, Luna-Guido M, Vanherck K, Dendooven L, Deckers J. Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. Applied soil ecology. 2007;37(1-2):18-30.
53. Zhang X, Qian Y, Cao C. Effects of straw mulching on maize photosynthetic characteristics and rhizosphere soil micro-ecological environment. Chilean journal of agricultural research. 2015 Dec;75(4): 481-7.
54. Singh B, Singh Y. Soil fertility: Evaluation and management. Soil science: An introduction. Indian Soc. Soil Sci. 2015; 649-69.
55. Khurshid KA, Iqbal M, Arif MS, Nawaz A. Effect of tillage and mulch on soil physical properties and growth of maize. International Journal of Agriculture and Biology. 2006;8(5):593-6.
56. Martínez-Cruz TE, Almekinders CJ, Camacho-Villa TC. Collaborative research on Conservation Agriculture in Bajío, Mexico: continuities and discontinuities of partnerships. International Journal of Agricultural Sustainability. 2019;17(3):243-56.
57. Muruganandam S, Israel DW, Robarge WP. Activities of nitrogen-mineralization enzymes associated with soil aggregate size fractions of three tillage systems. Soil Science Society of America Journal. 2009;73(3):751-9.
58. Chaudhary HP, Khan S, Uttam SK. Effect of nutrient doses and moisture conservation techniques on rainfed mustard in eroded soils of central Uttar Pradesh. Indian Journal of Soil Conservation. 2008;36(1):58-60.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/108675