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Tillage and mulching practices in cassava (*Manihot esculenta* Crantz): Influence on soil carbon mineralization, enzyme activity and glomalin content

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Abstract

A study was undertaken in laterite soils (Ultisols) in 2017 to find out the effects of continuous adoption of different tillage and mulching practices on carbon and nitrogen mineralization. Soil physico-chemical properties and biological parameters *viz*., soil enzyme (as an indicator of soil biological activity) and glomalin content (as an indicator of soil carbon sequestration) were estimated to find the relationships with the mineralization rate. Surface soil samples (0-0.15 m) from five treatments involving four tillage and mulching treatments each with three replications and a control were taken for the study. Results showed that maximum water holding capacity (WHC) of 41.3% was found in soils under conventional tillage with sheet mulching (T1) as compared to 37.7% in control (T5) with optimum BD (1.41 Mg m^{-3}) and porosity (46%). No significant differences in soil pH were observed among tillage practices. The soil organic carbon registered a maximum value under T5 (1.37%). A significant increase of carbon mineralization was noted in T1 (137.7 mg CO_2 100 g^{-1} soil) followed by minimum tillage with mulching (T3). The maximum mineralization of nitrogen, dehydrogenase activity, total glomalin (TG) and easily extractable glomalin (EEG) were recorded with control (T5). Results indicated that adoption of conventional tillage with porous ground cover sheet mulching practices increased soil carbon mineralization activity to an extent of 18.2, 19.3 and 28.6% over minimum tillage with mulching at 24 h, 48 h and 7 days, respectively. Among the soil properties, conventional tillage practices increased the soil bulk density insignificantly and the water holding capacity to an extent of 15.6% over minimum tillage.

Keywords: Minimum tillage, Soil Glomalin, Carbon mineralization, Soil dehydrogenases

Introduction

Conservation tillage system has a primary objective on reduction of soil and water losses due to reduced traffic operations, thereby decreasing soil compaction and costs for labour and other equipment. In soil ecosystems, the rate of organic matter decomposition, soil microbial enzymatic activity and carbon sequestration are interrelated to each other, and the rates are determined by initial soil management practices such as types of tillage such as conventional tillage, minimum tillage and mulch tillage etc., as well as fertilizer rates and applications of other amendments.

Organic matter decomposition, especially the process of carbon mineralization in soils is the most important ecological process mediating energy flux and nutrient cycling in terrestrial ecosystems. It has been attributed

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that this process is critically linked to the diversity of enzymes produced by the microbial community. Specially, dehydrogenase activity in soil provides correlative information on the soil metabolic activity corresponds to microbial populations. Soil microbes play a key role in the microbial process of nutrient cycling that involves soil organic component or compounds fragmentation, distribution and mineralization. This is closely linked with the build-up and maintenance of organic matter content and physical structure of soils, soil plant relations and decides the productivity capacity of soils. It is argued and even proved that soil microbiological activity indicators, soil glomalin content are quite sensitive and they can be successfully used in soil sustainability studies.

Glomalin-related soil protein (GRSP) can be produced specifically by Arbuscular Mycorrhizal Fungus (AMF). The efficient glomalin-producing AMFs include *Acaulosporamorroaiae, Glomus luteum, Glomus verruculosum, and Glomus versiforme*. A glycoprotein called glomalin, which contains 30 and 40 percent carbon (C), has been found to be enduring and stable in soil. Due to its high carbon content and aggregate stability, glomalin can sequester more carbon in the soil. In terrestrial ecosystems, higher aggregate stability promotes high organic carbon conservation (Hossain, 2021). To increase soil aggregation, glomalin, and soil organic carbon (SOC) content, zero tillage is recommended combined with crop residue retention and diverse cropping. Glomalin serves an important role in soil aggregation as stable glue (Wright et al., 2007).

Agricultural productivity depends both on management practices as well as soil microbiological dynamics, which in turn is affected by the former. In India, cassava is a major starchy as well as edible root crop and is cultivated in an area of 1.83 lakh ha and with a tuber production of 6.941 lakh tones in the year 2021 (based on estimates of FAO) in major soil type's *viz.,* Alfisols, Ultisols and Vertisols predominantly in the states of Kerala and Tamil Nadu. Farmers follow varied adoption of conventional tillage practices with 3-4 initial ploughings, which leads to abnormal mineralization of C and N and resulting in gaseous loss as CO_2 into the atmosphere. Besides, there are well established indicators of soil carbon sequestration as measured by the content of soil Glomalin (Total Glomalin (TG)) and easily extractable Glomalin (EEG), which are not exploited and adequately researched in India in general and laterite soils subjected to continuous cultivation of these practices, particularly in cassava. Therefore, this study was conducted to assess the effects of tillage on soil mineralization of carbon and nitrogen as well as their interaction with soil properties especially glomalin content.

Materials and Methods

The field work was undertaken at the farm of ICAR-CTCRI as part of study in the third year under the institute project on soil tillage experiment taken up during 2015-20. Surface soil samples (0-0.15 m depth) were collected after the second crop harvest season from two tillage systems and mulching treatments and each of the four treatments were replicated thrice in a Randomized Block Design. The treatment details are as: T1- Conventional tillage with porous weed control ground cover mulching (referred as sheet mulching), T2- Conventional tillage without mulching, T3- Minimum tillage with sheet mulching, T4- Minimum tillage without mulching and T5-Control (without tillage and mulching practice). The land was given with initial ploughings, two times to a depth of 0.22 m using tractor drawn disc plough for conventional tillage. In minimum tillage, soil was disturbed manually during times of initial ridge formation and two times during earthing up operations. Control refers to cultivable lands wherein no tillage and mulching practices performed.

The soil of the experimental site is typical laterite with strongly acidic pH (3.8-4.6). The basic soil physical constants viz. bulk density, particle density, total porosity, water holding capacity were determined using Keen Roczkowski box method as described by Piper (1966). Soil pH was determined with 1:2.5 ratio soil: water suspension (w/v) using pH meter (Jackson, 1973). Soil organic carbon (SOC) was determined by dichromate oxidation method (Walkley and Black, 1934). Dehydrogenase enzyme activity was estimated with 2-3-5-Triphenyl tetrazolium chloride (TTC) reduction technique (Casida, 1977). Carbon mineralization was monitored at 24 h, 48 h and 7 days with organic matter decomposition technique in soil through CO_2 evolution by alkali trap method (Zibilske, 1994). Nitrogen mineralization was determined with micro diffusion method (Conway, 1942). Total glomalin (TG) and easily extractable glomalin (EEG) were determined by the Lowry protein assay with bovine serum albumin standard (Wright and Upadhyaya, 1996).

Results were evaluated by statistical analysis. F-test analysis of variance was performed, and significant difference was calculated at 5% level probability. The effects of treatments with control as well as the differences among the treatments are examined to prove the significant differences. Pearson's correlation was performed in order to seek the relationships between each physical and biological soil variables. Statistical analysis was performed by Wasp 2.0 package for windows (ICAR-CCARI, Goa) and with Microsoft Office Excel programs.

Results and Discussion

Soil physico-chemical properties

The effects of treatments on soil physicochemical properties are given in Table 1.

Table 1. Effect of different tillage and mulching treatments on soil parameters

Treatment	Physico-chemical parameters*				
	Bulk density (Mg m^{-3})	Porosity (%)	Water holding capacity (%)	pH	Soil organic carbon (%)
T1	1.41^{bc}	45.6^{a}	41.3^{a}	3.25^{b}	0.54^{b}
T2	1.45^{bc}	38.9^{b}	34.4^{c}	3.86^{a}	0.54^{b}
T3	1.38^{c}	35.5^{bc}	35.7^{bc}	3.85^{a}	0.60^{b}
T4	1.48^{b}	31.6^{c}	38.4^{ab}	3.89^{a}	0.74^{b}
T5	1.58^{a}	38.4^{b}	37.7^{abc}	3.86^{a}	1.37^{a}
CD (P = 0.05)	0.092	6.54	3.81	0.36	0.21
CV (%)	3.5	9.5	5.6	5.3	15.2

*Values followed with different superscript alphabets are significantly different at P = 0.05

Among the physical properties, soil bulk density and porosity were observed to be optimum in tilled soils and higher value (1.58 Mg m^{-3}) is noticed in control (Table 1). This could be the resultant effect of tillage on loosening the soil as reported previously by Agbede (2006). The maximum WHC (41.3%) was recorded in conventional tillage with sheet mulching (T1) followed by minimum tillage without sheet mulching (T4). Bulk density of the soil was decreased in conventional tillage as compared to control due to increased porosity that resulted in higher water holding capacity of the soil. The result supports the findings of Gerhardt (1997) and Kumar et al., (2015).

There is not much significant change in soil pH because of various tillage practices. However, there was a significant decrease in pH of conventionally tilled soils as compared to control. It has been reported that minimum tillage and conventional tillage lowered pH in the 0-5 cm layer compared to no tillage (Chan et al., 1992) or that tillage did not affect pH (Standley et al., 1990).

The soil organic carbon registered the maximum in control (T5). Minimum tillage practices helped in preserving carbon, as evident from the higher values, though not significant, as compared to conventional tillage probably due to reduced soil disturbance and increased additions of plant biomass. Conservation practice showed net positive effect on increase in depth wise soil organic carbon (SOC) and microbial biomass carbon (MBC) both of which can influence chemical, physical and biological properties (Crystal-Ornelas, 2021). It is also suggested that strong link between accumulations of SOC and microbial community traits under conservation tillage practices pave a way to sustainability of agro-ecosystems. The findings of Rahmati et al., (2020) agree with the result, which concluded that minimum and zero tillage significantly improved the SOC as primary indicator of soil quality. Liu et al., (2020) suggested that conservation tillage could be a viable technology to alleviate the deleterious effect of climate change via carbon sequestration and reduction of green-house gas emission from agricultural activities into the atmosphere. Additionally, it enhances the sustainability of the agricultural production system and resilience to external stresses.

Soil biological properties

The content of dehydrogenase enzyme among the tillage treatments ranged from 0.46-1.25 μg TPF $g^{-1}h^{-1}$ (Table 2).

Table 2. Influence of different treatments on soil biological parameters

Treatment	Soil biological parameters*		
	Dehydrogenase activity (μg TPF $g^{-1}h^{-1}$)	Total Glomalin (mg g^{-1})	Easily extractable Glomalin (mg g^{-1})
T1	1.06^{b}	2.64	0.15^{bc}
T2	0.82^{c}	1.94	0.12^{c}
T3	0.75^{c}	2.59	0.15^{bc}
T4	0.46^{d}	2.46	0.17^{ab}
T5	1.25^{a}	2.70	0.20^{a}
CD (P = 0.05)	0.186	NS	0.044
CV (%)	11.8	18.3	15.2

*Values followed with different superscript alphabets are significantly different at P = 0.05

The maximum content of DHA was measured in control whereas considerable variation was observed among the treatments with and without mulching under both tillage practices. It was found that DHA depends on the availability of soil carbon and a positive correlation between DHA and the labile carbon concentration was reported (Wiatrowska et al., 2021). Dehydrogenase indicates the metabolic activity of soil organisms, especially bacteria and fungi in the soil (Chu et al., 2007; Jarvan et al., 2014; Sharma and Mishra, 1992) and reflects the microbial redox system and the oxidative activities in soil. Abundance of fungi in conservation tillage (CT) as compared to conventional tillage contributed towards high DHA due to vast amounts of soil C which amplified the soil DHA. The enormous amount of soil carbon in CT encourages the expansion of fungi, which increases soil enzyme activity.

The content of total glomalin among the tillage and mulch treatments ranged from 1.94-2.70 mg g^{-1}. The maximum content of TG was registered in control, but no statistical significance had been observed with other treatments. The content of easily extractable glomalin (EEG) among the treatments ranged from 0.11-0.20 mg g^{-1}. The control treatment recorded the maximum value of 0.20 mg g^{-1} and considerable variation was observed among the treatments. The no-tillage system enhanced easily extractable glomalin contents in the soil surface layers that linked to soil aggregation (Bortolini et al., 2021). In the long run, reduced soil disturbance may be beneficial for the growth of fungi. Therefore, reducing the amount of tillage increased soil health by encouraging soil carbon sequestration and aggregate stability through fungal development as well as the glomalin content. The favorable correlation between N mineralization and EEGRSP (Easily Extractable glomalin Related Soil Protein) reported by previous studies also suggests that EEGRSP may be employed as a measure of soil N availability under a no-till system. The favorable effects of minimum tillage on improved SOM, carbon storage may be due to a positive association of glomalin with water stable aggregates which is maintained favorably by zero tillage during the full crop year. The positive glomalin-WSA association that indicates intact fungal hyphal networks is not preserved by conventional tillage, even though it may increase soil glomalin at various times of the cropping year (Wilkes et al., 2021).

Carbon and nitrogen mineralization

The content of carbon mineralization at 24 hours among the tillage treatment ranged from 62.3- 95.3 increased to 48 hours and later decreased (Table 3). Maximum quantity of mineralized C (as carbon dioxide) was observed in soils under conventional and minimum tillage with sheet mulching (T1, T3 and in T5) probably due to higher content of soil carbon and increased activity of dehydrogenases. More quantity of particulate organic carbon (POC) in minimum disturbed lands may also contribute to the development of macro-aggregates and aggregate stability at 0–10 cm depth, protecting SOC from mineralization and could be attributed to the differences in mineralization potential of minimum tillage as compared to conventional tillage (T1 versus T3). Additional SOC sequestration may be affected by lengthening the conservation tillage period as explained by Kan et al., (2020). The content of carbon mineralization at 48 hours among the tillage treatment ranged from 99-135.7 mg CO_2 100 g^{-1}. Though there is an increased decomposition noticed in the treatments of conventional tillage with sheet mulching and minimum tillage with sheet mulching, it was not statistically significant. The amount of mineralizable carbon in 7 days among the tillage treatment ranged from 58.3-128.3 mg CO_2 100 g^{-1}. The treatment minimum tillage without mulching recorded the maximum value of 128.3 and considerable variation was observed among the treatments. It was reported that C mineralization was more abundant in soils with minimum physical disturbance, associated with species that could produce extracellular polymeric compounds and had metabolic adaptations for withstanding environmental stress. It is important to understand how soil physical disturbance affects microbial communities across climates and intrinsic soil qualities that contribute changes in C mineralization. According to Vazquez *et al.* (2019) conservation tillage techniques with minimum inversion techniques hasten the mineralization of C, enhance soil C content, and boost microbial biomass and activity.

The content of nitrogen mineralization at 24 hours among the tillage treatment ranged from 2.3-3.7 mg N 100 g^{-1}. Mulching reduced the nitrogen mineralization significantly especially in minimum tillage practices

Table 3. Changes in soil C and N mineralization over time in different treatments

Treatment	C mineralization			N mineralization		
	24 h	48 h	7 days	24 h	48 h	7 days
	(mg CO_2 $100g^{-1}$)			(mg N $100g^{-1}$)		
T1	95.3^{a}	135.7	66.0^{b}	2.3^{c}	1.6	1.0^{b}
T2	66.0^{bc}	110.0	58.7^{b}	2.5^{bc}	1.6	0.9^{b}
T3	80.7^{abc}	113.7	51.3^{b}	2.6^{bc}	1.3	0.9^{b}
T4	62.3^{c}	99.0	128.3^{a}	3.7^{a}	1.5	1.2^{ab}
T5	88.0^{ab}	102.7	110.0^{a}	2.9^{b}	1.6	1.4^{a}
CD (P = 0.05)	23.7	NS	29.7	0.52	NS	0.33
CV (%)	16.6	16.4	16.7	10.3	10.3	16.6

*Values followed with different superscript alphabets are significantly different at P = 0.05

(Table 3). Lingutla et al., (2019) observed that conservation tillage practices significantly improved the microbial parameters, total nitrogen (total N), mineralizable nitrogen (MN), microbial biomass nitrogen (MBN), and microbial biomass carbon (MBC). The content of nitrogen mineralization at 48 hours among the tillage treatment ranged from 1.34-1.63 mg N 100 g^{-1}. Though there is an increased decomposition noted in control and conventional tillage system, no statistical significance was observed. The content of nitrogen mineralization in 7 days among the tillage treatment ranged from 0.93-1.40 mg N 100 g^{-1}. The treatment control recorded the maximum value of 1.40, considerable variation was observed among the treatments. Vazquez et al., (2019) concluded that it is possible to perceive the more significant effect of no tillage net nitrogen mineralization (NNM) than on C mineralization as a decoupling between the C and N mineralization, which may boost the availability of N for crops and reduce the risk of N losses during the fallow season. The positive effects of long-term no-till management on soil nitrogen stocks, nitrogen mineralization, and effective availability of N are demonstrated by the results of Canisares et al., (2021). From the above study, the minimum tillage favored higher status of carbon, nitrogen mineralization and with improved soil properties. The amounts of SOC and total nitrogen retained in the soil have increased due to enhanced residue retention and minimum tillage methods (Salahin et al., 2021).

Correlation among soil parameters influencing C and N mineralization

Carbon and nitrogen mineralization at 24 hours were significantly correlated ($t=2.28^*$; $P=0.05$) with each other. Soil water holding capacity is found to be the major variable associated with the mineralization of C (3.59^*). Similarly, nitrogen mineralization at 7 days was found to be significantly correlated with soil organic carbon (4.06^*) and EEG (3.20^*). Among the soil properties, a positive correlation was found among SOC with bulk density (3.71^*) and EEG (3.54^*), TG and EEG (4.8^*), DHA activity with bulk density (2.52^*) and total glomalin with water holding capacity (2.34^*). The association of EEG with soil properties indicated the favorable relationship among soil organic carbon, soil dehydrogenases and nitrogen mineralization at 7 days of incubation.

Conclusion

The metabolic activity as measured by dehydrogenase content influenced the carbon mineralization at 24 h and 7 days. There was no significant influence of tillage and mulching practices on total glomalin content. Soils where no tillage practices performed were found to have high EEG content as compared to conventional and minimum tillage practices. Based on the results obtained from the study, it can be inferred that conventional tillage and porous weed control plastic mulch with a thickness of 120 gsm treated soils can be an ideal practice in Ultisols in view of optimum water holding capacity and its effect on soil carbon mineralization.

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