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Soil Carbon Fractions, Growth and Yield as Affected by Different Nutrient Management in Fodder Maize (*Zea mays* L.)

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A B S T R A C T

The present study investigated the effect of different nutrient management practices on soil C fractions, growth and yield of fodder maize variety- African tall. The treatments were seven in number - T_1: POP recommendation, T_2: Soil test based POP, T_3: Organic nutrient management using TOF-F, T_4: POP + AMF, T_5: Soil test based POP + AMF, T_6: Organic nutrient management + AMF, and T_7: Absolute control. Among the soil C fractions, highest TOC content was recorded by T_3 which was on par with T_5 and T_6 and highest DOC content was observed for T_1 at both levels of sampling depths. The soil labile and recalcitrant fractions followed same trend at both levels of depth of sampling i.e. T_5 was found to be superior which was on par with T_6. The highest value for shoot weight, root volume, green fodder and dry fodder yield was observed in treatment T_5 which was on par with T_4. The root weight was higher for organic nutrient and AMF combination treatment – T_6 (50.23 g/plant). The results indicated an increased AMF activity in soil test based and organic manured treatments and inoculation with AMF resulted in better growth and yield of fodder maize in all the treatments. The correlation study indicated a strong positive correlation between labile and recalcitrant soil C fractions and fodder yield of maize giving an insight to the importance those C fractions in microbial growth, nutrient cycling, and plant growth.

Introduction

Soil organic carbon (SOC) is one of the most widely used soil quality indicators which affects various soil chemical, physical and biological properties and plays a primary role in multiple soil functions in agricultural soils, such as nutrient cycling, soil aggregate formation, water retention and habitat provision for biodiversity (Else *et al.,* 2019). Soil organic carbon also plays an important role in climate regulation, with the potential of increasing carbon sequestration, offsetting fossil-fuel emissions and counteracting yield reduction created by extreme weather events (Lal, 2004). Among the soil C fractions, labile carbon which exhibit characteristics of fast decomposition has potential as an indicator of

soil functions, in particular: nutrient cycling, soil aggregate formation, carbon sequestration and habitat provision for biodiversity (Else *et al.,* 2019). On the other hand, recalcitrant carbon pools (RCP) take more time to decompose and are not readily available to microorganisms (Lal, 2004). The RCP can be represented by humic substances (humin-HU, humic acid-HA, and fulvic acid-FA).Therefore, both pools recalcitrant and labile can elucidate how the soil has been used and which management is adequate to increase carbon stocks, mainly in tropical conditions (Stevenson, 1994). Agricultural measures that are aimed at increasing SOC stocks are therefore becoming a priority worldwide. AMF are soil borne fungi that have the capability to improve plant nutrition by increasing the availability as well as translocation of various nutrients especially phosphates and increases the resistance to several abiotic stress factors (Rouphael *et al.,* 2015; Sun *et al.,* 2018; Begum *et al.,* 2019). Formation of hyphal network by the AMF with plant roots significantly enhances the access of roots to a large soil surface area, causing improvement in plant growth (Bowles *et al.,* 2016) and also improves the soil quality by influencing its structure and texture (Thirkell *et al.,* 2017).

Besides that fungal hyphae can expedite the decomposition process of soil organic matter as priming effects mediated by AM hyphal exudation can support microbial communities mineralizing SOM and thereby extend plant-mediated impacts on C and N cycling beyond the rhizosphere (Paterson *et al.,* 2016).

Despite the importance of SOC, its depletion is one of the main threats for agricultural soils. The fortification of organic manures, retention of crop residues, reduced tillage practices, use of bio fertilizers, integrated nutrient management techniques and improved varieties of field crops, soil test based fertilizer

applications etc are some of the attempts to enhance organic C levels in soil and to attain agricultural sustainability and profitability. Numerous studies have examined the long-term effects of residue management and fertilization on SOC and labile organic C fractions. Little attention has been paid to the short-term effects of different nutrient management practices on C fractions in soil.

The present study was conducted to evaluate the effect of nutrient management on soil C fractions, growth and yield parameters of fodder maize.

Materials and Methods

The experiment was conducted during June-August, 2020 using fodder maize variety - African Tall as the crop under conventional tillage and irrigated conditions at the College of Agriculture, Vellayani, KAU. The treatment details were listed below.

T_1: Package of practices (POP) Recommendation

T_2: Soil test based POP

T_3: Organic nutrient management (using thermochemical fortified organic fertilizer (TOF-F)

T_4: POP + AMF (Arbuscular mychorrhizal Fungi)

T_5: Soil test based POP + AMF

T_6: Organic nutrient management + AMF

T_7: Absolute control

The thermochemical organic fertilizer was prepared as per patented KAU - Suchitha technology (Sudharmaidevi *et al.,* 2017). Fresh waste was ground to uniform

consistency in the grinder unit of the KAU - Suchitha waste processing machine and was boiled at 100 ^{0} C in the reactor unit after adding the chemical reagents like HCl (0.25 N, 50 ml kg^{-1} waste) for 30 min followed by KOH (0.5 N, 100 ml kg^{-1} waste) for 30 min. Processing was completed within one hour and TOF was produced. Coir pith @ 40 g kg^{-1} waste and charcoal powder @ 30 g kg^{-1} was added and sun dried to reduce the moisture content.

The TOF-F was prepared for the study by fortifying the TOF with N (1.5%) as groundnut cake, P (1%) as rock phosphate, Ca (1%) as calcium carbonate, Mg (0.5%) as magnesium sulphate, Zn (50 ppm) as zinc sulphate, and B (5 ppm) as borax.

The POP recommendation (KAU, 2016) was followed and organic manures were applied in terms of nitrogen equivalence for treatments T_3 and T_6. The AMF was applied @5 g per plant. The treatments T_2 and T_5 were fixed as per POP soil test based recommendations for field crops.

The soil samples were collected from two depths – 0-20 cm and 20-60 cm and were analyzed for different C fractions as per standard methods.

The total organic C (TOC) content by weight loss on ignition (FAI, 2017), dissolved organic C (DOC) - titrimetry (Jones and Willet, 2006), labile carbon (LC) – KmnO$_4$ oxidation (Blair *et al.,* 1995) and recalcitrant carbon (RC) - modified Walkley and Black titration (Chan *et al.,* 2011), The growth and yield parameters were also recorded from the observational plants at milky cob stage of fodder maize.

Statistical analysis were done for all parameters by standard procedures using ANOVA table developed using statistical software – GRAPES (Gopinath, 2021)

Results and Discussion

Effect of nutrient management practices on soil C fractions

The highest soil TOC content was recorded in treatment T_3 which was on par with T_5 and T_6 at both depths of sampling. The treatment T_1 had highest DOC value at the two depths of sampling followed by T_4 and lowest value was for treatment T_7. Regarding the LC, the highest value was observed for T_5 which was on par with T_6 followed by T_4 and lowest value was for control at both levels of sampling depths. The RC content in soil followed the same trend of LC at both levels of sampling depths.

As it is evidenced from Table 1, all the C fractions had lower values at 20-60 cm than at 0-20 cm depth. The SOC fraction is directly derived from recent plant inputs, whether surface deposition of aboveground litter or root turnover, which decreases exponentially with depth, and has a relatively short mean residence time (Sanderman *et al.,* 2021). For most soils, where vertical transport is on the order of a 0.5–2.0 mm year^{-1} (Kaste *et al.,* 2007), this means that most SOC is mineralized or transformed into more stable forms by microbial cycling before moving deeper in the soil profile. The treatment of organic nutrient management – T_3 and T_6 were found to be superior in soil TOC content than other nutrient management practices revealing the effect of organic manures in enhancing the soil organic carbon levels as universally accepted and reported (Voltr *et al.,* 2021). AMF can explore and multiply more in organically manured and soil test based fertilizer application treatments. The treatments with AMF combination had higher soil LC and RC content and among them organic nutrient management and soil test based fertilizer application were found to be superior. This result would be consistent with

the interaction of these hyphae and their associated microbiota being particularly efficient in priming of SOM mineralization.

This could occur through greater effects of hyphal exudates on components of the microbiota active in SOM mineralization, greater hyphal access to potentially mineralisable SOM or a combination of both mechanisms (Paterson *et al.,* 2016).

Effect of nutrient management practices on growth and yield

The treatment T_4 had highest value for plant height followed by T_5 which was on par with T_6. The shoot weight, green fodder yield and dry fodder yield showed a similar trend where T_5 recorded highest value which was on par with T_4 followed by T_6. Regarding the root weight T_6 had highest value followed by T_5. The treatment T_5 had higher root volume also. The treatment T_5 which was the combination of soil test based POP and AMF produced highest shoot biomass which resulted in its higher green fodder as well as dry fodder yield. The above result hinted to the fact that inoculation of AMF can enhance the concentration of various macro-nutrients and micro-nutrients significantly, which leads to an increased photosynthate production and hence resulted in increased biomass accumulation (Chen *et al.,* 2017; Mitra *et al.,* 2019).

Table.1 Effect of different nutrient management on soil C fractions at two depths of sampling

Treatments	0-20 cm				20-60 cm			
	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %	TOC %	DOC mg kg^{-1}	LC mg kg^{-1}	RC %
T_1	3.06^{bc}	33.44^a	720.26^d	0.94^d	2.90^{bc}	29.48^a	547.68^d	0.70^d
T_2	3.03^c	30.49^c	765.75^c	1.18^c	2.87^c	26.61^c	598.26^c	0.95^c
T_3	3.20^a	27.14^e	783.14^c	1.48^b	3.04^a	23.30^d	618.92^{bc}	1.12^b
T_4	3.03^c	31.81^b	830.72^b	1.42^b	2.89^{bc}	28.40^b	644.99^b	1.19^b
T_5	3.12^{abc}	28.79^d	897.00^a	1.74^a	2.99^{ab}	27.22^c	708.30^a	1.26^a
T_6	3.15^{ab}	25.04^f	879.81^a	1.77^a	3.02^a	23.45^d	697.64^a	1.30^a
T_7	3.02^c	33.06^a	645.12^e	0.86^d	2.89^{bc}	21.13^e	452.88^e	0.63^e
SEm (±)	0.035	0.282	11.146	0.027	0.035	0.296	9.218	0.02
CD (0.05)	0.109	0.868	34.346	0.082	0.106	0.912	28.403	0.062

Table.2 Effect of different nutrient management on growth and yield of fodder maize

Treatments	Plant height (m)	Shoot weight (g)	Root weight (g)	Root volume (g/cm^3)	Green fodder yield (tonnes /ha)	Dry fodder yield (tonnes/ha)
T_1	2.14^{cd}	181.35^{bc}	33.25^d	38.00^c	39.90^{bc}	7.98^{bc}
T_2	2.10^{cd}	174.75^{cd}	26.97^e	32.55^d	38.44^{cd}	7.69^{cd}
T_3	1.99^e	174.97^{cd}	32.32^d	29.55^e	38.49^{cd}	7.70^{cd}
T_4	2.35^a	193.91^a	42.00^c	40.13^b	42.66^a	8.53^a
T_5	2.23^b	195.99^a	46.06^b	45.12^a	43.12^a	8.62^a
T_6	2.17^{bc}	186.81^b	50.23^a	38.36^c	41.10^b	8.22^b
T_7	2.07^d	174.13^d	28.10^e	29.04^e	38.31^d	7.66^d
CD (0.05)	0.078	6.678	0.697	1.641	1.47	0.29
SEm (±)	0.025	2.167	2.149	0.533	0.47	0.09

Table.3 Correlation matrix for green fodder yield of fodder maize with soil C fractions at different depths

a) 0-20 cm depth					
	TOC	DOC	LC	RC	GFY
TOC	1				
DOC	0.266	1			
LC	0.623**	-0.243	1		
RC	0.448*	-0.571**	0.922***	1	
GFY	0.763***	0.332	0.811***	0.572**	1

a) 20-60 cm depth					
	TOC	DOC	LC	RC	GFY
TOC	1				
DOC	0.347	1			
LC	0.58**	0.446*	1		
RC	0.455*	0.203	0.945***	1	
GFY	0.786***	0.654**	0.727***	0.585**	1

*** Correlation is significant at 0.001 level (two tailed)
** Correlation is significant at 0.01 level (two tailed)
* Correlation is significant at 0.05 level (two tailed)

Correlation analysis between green fodder yield and soil C fractions

A significant and positive correlation was obtained between green fodder yield (GFY) and soil LC and RC at both levels of sampling depths which indicates the importance of labile and recalcitrant C among other C fractions and can be used as soil indicators to assess the short term effects of nutrient management.

The labile and recalcitrant carbon fractions were strongly and positively correlated to fodder yield in maize. The use of an appropriate combination of fortified organic fertilizers or chemical fertilizers in combination with AMF depending on soil fertility status is a step forward for providing balanced nutrition to crops and increasing profit for farmers. The AMF must be explored at all levels to further investigate their role in nature as a bio-fertilizer for sustainable agricultural production.

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