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Short-term effect of soil tillage and NPK fertilization rates on soil carbon sequestration and yield of *Colocasia esculenta* Schott in two micro-environments in SE, Nigeria

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ABSTRACT

Quantification of soil organic carbon cycling as impacted by soil and crop management practices is required for C storage and soil quality improvement investigations. This study assessed the short-term effect of conventional tillage (CT) and No-Tillage (NT) practices on SOC sequestration and yield of cocoyam (*Colocasia esculenta*). The experiment was conducted simultaneously at two locations (06◦52' N, 07◦15' E and 06◦ 26' N; 07◦16' E) in southeast Nigeria. A Randomized Complete Block Design with five replications and four treatments comprised of CT and NT, respectively, with 150 and 300 Kg ha^{-1} of NPK 15:15:15, was used. Soil quality attributes were measured at two soil depths (0-20 cm and 20-40 cm) in both locations and analyzed. The results indicated that the quantity of carbon sequestered in the soil at 0-20 cm soil depth for both sites was 46.7-90.9 and 65.0-117.9 Mg ha^{-1}, respectively, for the two planting seasons in NT plots treated with 300 Kg ha^{-1} of NPK. This was followed by NT plots treated with 150 Kg ha^{-1} of NPK, which sequestered 55.5-86.2 and 46.7-91.9 Mg ha^{-1} SOC. CT plots that received 300 Kg ha-1 NPK with 11.3-47.6 Mg/ha SOC had 44% and 28% lower stored SOC when compared to NT, NPK 150 Kg ha^{-1} plots for the two-planting season respectively. This indicates that CT practices significantly limit SOC sequestration. CT with 300 Kg of NPK 15:15:15 gave the highest corm yield, followed by No-till with 300 Kg ha^{-1}. A better edaphic condition provided by CT was compensated for by higher doses of N fertilizer in NT Plots.

1.0. Introduction

Soil carbon (C) sequestration implies the removal of atmospheric greenhouse gas, by plants and storage of the fixed C through incorporation into soil organic matter. Leading agronomic and related practices that can be helpful in SOC sequestration include: incorporation of cover crops; adoption of no-tillage (NT) or minimum tillage; adoption of ecological and soil health-friendly cropping systems; use of mulches in the form of crop residues; reduction of soil and water losses by surface runoff and erosion; adoption of integrated nutrient management practices to increase of soil fertility; use of organic amendments; and promotion of Agro-forestry (Tanveer et al., 2019).

Tillage is the physical perturbation of soil, performed to create conditions desirable for germination of seeds, seedling emergence, and root growth to reduce competition from weeds (Priher et al., 2000). Intensive and continuous tillage may cause enormous losses of soil organic carbon (SOC), thus inducing an increase in soil erosion and breakage of soil structure (Melero et al., 2009). As a consequence, agricultural practices that reduce soil degradation are needed to improve soil quality and agricultural sustainability. Conservation tillage minimizes soil disturbances, protects the soil against deterioration, and enhances durability (Melero et al., 2009). It is widely recognized that tillage results in depth stratification of many soil properties such as soil organic carbon (SOC) and Nitrogen (Franzluebbers, 2002). Brye et al., 2006. Moreno et al., 2006) noted that nutrients, aggregate stability, porosity, microbial biomass, and enzyme activities (de Moraes Sa and Lal, 2009) are affected by soil physical manipulation. Different investigations have demonstrated that conventional tillage and nitrogen fertilization may drain soil organic matter level by upgrading C mineralization and restricting C inputs (Cambardella and Elliott, 1993). That conservation tillage and nitrogen fertilization can build up C storage and dynamic C fractions in the surface soil (Sainju et al., 2002, 2006).

Lal and Kimble (1997) demonstrated that the transformation of conventional till (CT) to no-till (NT) could sequester atmospheric CO_2 by 0.1% ha^{-1} at 0 to 5 cm per year or by an aggregate of 10 tons in 25 to 30 yr. Be that as it may, the elements of progress will rely upon soil texture and other soil factors.

Measurement of soil carbon (C) cycling as affected by soil management is required for C sequestration and soil quality improvement studies. Carbon sequestration, utilizing long-term improved agronomic practices, is required not exclusively to build soil C stocks for C trading and to moderate greenhouse gas emissions, for example, CO2, from the soil profile but in addition to improve soil quality and increase crop productivity (Sainju et al., 2008).

As indicated by Franzluebbers et al., (1995), knowledge of soil C cycling in the terrestrial ecosystem is needed for a better understanding of carbon sequestration dynamics in the ecosystem. The SOC is a C fraction that changes slowly with time, and it is used to measure C sequestration. It is also a useful component of soil quality and productivity evaluations.

Cocoyam belongs to a group of crops called roots and tubers. They are known to be a corm plant. Root and tubers are the major carbohydrate staples in most countries of West Africa. In Nigeria, it is estimated that 31 million tons of root and tubers such as cassava, yam, sweet potatoes, cocoyam itself, etc. are produced annually (Onwueme & Wiston, 1994). Cocoyam is an ecologically unique crop. It can grow in ecological conditions (waterlogged soils, shaded environment, etc.), which other plants may find severe or adverse (Anikwe et al., 1999). Cocoyam also requires an average daily temperature of above 210C for regular production and able to tolerate heavy soils, and it does best in soil pH 5.5-6.5 (Onwueme, 1999). Its production, however, may be hampered by lack of adequate amounts of soil nutrients as it is high soil fertility demanding crop and can react to many soil amendments and manipulations (Agbede, 2008). A large portion of the ecological constraints in the cocoyam production can be effectively tackled and possibly solved with adjustment of the farming systems like conventional and conservational tillage practices and mulching, especially using different nitrogen (N) rates have not been studied to a great extent in southeast Nigeria (Anikwe et al., 2007). The effects of tillage, cropping systems, and N fertilization on soil C fractions have been studied extensively (Kuo et al., 1997; Sainju et al., 2006). Information is not readily available on the combined effects of cropping system, tillage, and inorganic N fertilization on SOC sequestration on the short run in degraded Ultisols with kaolinitic clay mineralogy and isohyperthermic temperature regimes in the southeastern part of Nigeria.

We hypothesized that soil tillage variants, inorganic N fertilization, and intensive cropping would influence soil carbon sequestration even in the short term. This study aims at determining the short-term effect of conventional and conservation tillage practices and NPK fertilization rates on soil organic carbon sequestration and yield indices of cocoyam (*Colocasia esculenta*) in two agro environments in southeast Nigeria.

2.0. Materials and methods

2.1 Description of experimental sites

The experiment was carried out in the 2013 and 2014 cropping seasons at two locations in southeastern Nigeria. The first site was at the Faculty Experimental Farm of the Faculty of Agriculture and Natural Resources Management, Enugu State University of Science and Technology, Nigeria (06°52' N, 07◦15' E; mean elevation 450 m above sea level). The area has an annual rainfall of 1700–2010 mm. The site has a bimodal rainfall pattern that runs between April and October, and the dry season is between November and March. The soil's textural class is loam with an isohyperthermic soil temperature regime (Ezeaku and Anikwe 2006) and is classified as Typic Paleustult (Anikwe et al. 1999). The second site was at the experimental farm site of Enugu State College of Agriculture and Agro-entrepreneurship, Iwollo Nigeria (060 26' N; $07^{0}16'$ E). It has an annual rainfall of about 1800-2000 mm, which spread between April and November. The textural class is silt-loam (Ibudialo et al., 2011).

2.2 Field methods

The sites were slashed and cleared of grasses. At each location, a total area of 11 m x 20.5 m (225.5 m2) was set out for the work. The same plots were used to conduct the experiment in the 2013 and 2014 cropping seasons. The field was divided into 5 blocks with each block having 4 experimental units giving a total of 20 plots using randomized block design (RCBD). One-meter alleys demarcated the experimental units, and each unit (bed) measured 3 m by 3 m (9 m2). The testbeds were prepared manually with traditional hoes. The experimental units were made up of two rates (150 kg ha-1 and 300 kg ha-1 of NPK 15:15:15 Fertilizer and 2 tillage variants, viz. conventional tillage (tilled plots on 0-30 m raised beds) and no till plots on flatbeds. The treatment matrix included all four combinations of tillage and fertilizer treatments. The test crop was a cultivar of cocoyam (Colocasia esculenta Schott, [cultivar: ede ofe]) sourced from the National Root Crops Research Institute (NRCRI), Umudike, Nigeria. The criteria for selection of the cultivar was based on the fact that it is one of the most popular varieties grown around the zone. Cocoyam cormels that weighed 25–30 g were sown at one cormel per hole at five-centimeter depth using intra - inter-row spacing of 50 cm. A total of 35 cormels were planted in each plot making a plant population of 40,000 plants per hectare. Lost stands were replaced. Weeding was done at 21 days after planting (DAP) using traditional hoes, with subsequent rouging. NPK 15:15:15 fertilizer was applied using the banding method 28 DAP.

2.3 Observation and data collection

Four undisturbed soil core samples (for analysis of bulk density and hydraulic conductivity) and four auger samples [for determination of gravimetric soil water content (GWC)] N, P, K, Ca, Mg, Na, pH, organic carbon, cation exchange capacity (CEC) and textural class were randomly collected from two soil depths (0 to 20 cm and 20 – 40 cm) in each plot at 95 days after planting (DAP). The soil core samples collected using 98.2 cm^3 open-faced cores (195 mm diameter by 50 mm height) were analyzed individually, and mean results were used. In contrast, the auger samples were mixed and composite subsamples used for analyses. The soil physicochemical parameters were measured at 95 DAP. Corm yield was measured at harvest (270 DAP). For corm yield measurements, ten plants were randomly selected per plot, tagged, and weighed in a scale to get the fresh tuber weight, and the average is taken to give the tuber weight per plant.

2.3 Laboratory methods

A composite soil sample (collected from 10 points in the entire plot before the experiment started in 2013) and the samples collected within the experimental period were analyzed in the laboratory for total Nitrogen, available phosphorus, potassium, calcium, magnesium, sodium, pH, soil organic carbon, and cation exchange capacity. Total Nitrogen was determined by the macro Kjeldahl method (Bremner, 1982). Available Phosphorus was determined using the Bray II method, as outlined in Olsen (1982). Soil organic carbon was analyzed by the Walkley/Black procedure (Nelson and Sommers 1982). Soil pH in KCl was measured by the glass electrode pH meter (McLean 1982). The exchangeable cations and CEC were determined by the method described by Thomas (1982). Particle size distribution (PSD) was determined by the hydrometer method of Gee and Orr (2002). Dry soil bulk density was determined by the core method of Blake and Hartge (1986). The carbon stock in each plot was calculated using the formula: C (%)/100 × soil bulk density × area (1 ha) × soil depth [Anikwe 2010].

2.4 Data analysis

The data collected from the experiment were analyzed using analysis of variance test based on RCBD (using F-LSD at P=0.05) according to procedures outlined by Steel and Torrie (1980).

3.0. Results

3.1 Pre-planting soil properties

The pre-planting analysis of soil properties at both the Iwollo and Agbani sites are presented in Table 1. The results indicated that the Agbani site was made up of sandy silt while the Iwollo site was sandy loam. Percent organic carbon (1.68 %), organic matter (2.90 %) and nitrogen (0.126 %) in the Iwollo site was higher than that in the Agbani Site (1.08 %, 1.86 % and 0.056 %) respectively. This indicated that the Iwollo site had higher values for soil nutrients when compared to the Agbani site. The soil pH in water varied from 5.2 at the Iwollo site to about 5.5 at the Agbani site indicating "slightly acidic" for both sites according to the ratings of Landon (1985). The Iwollo site had higher exchangeable cations (CEC 23.20, Mg+ 2.20, K^+ 0.10, Na^+ 0.15, and Al^+ 0.40 Cmol kg^{-1}) while Agbani site had CEC 8.4, Mg^+ 1.20, K^+ 0.06, Na^+ 0.09, and Al^+ 0.27 Cmol kg^{-1}. The bulk density in both Iwollo and Agbani site was 1.52 and 1.46 Mg m-3, respectively, while the Iwollo site had 39.25 % total porosity, and the Agbani site had 46.04 % total porosity. Saturated hydraulic conductivity of 30.30 cm3 /hr was found in the Iwollo site, while 21.72 k cm^3 hr^{-1} was found at the Agbani site.

3.2 Effect of tillage and NPK fertilization rates on carbon sequestration

The result showed significant treatment differences (P=0.05) in soil organic carbon stored in the Iwollo and Agbani experimental sites at 0-20 cm and 20-40 cm depths and planting seasons (2013 and 2014), respectively (Table 2). The quantity of carbon stored in the soil at 0-20cm soil depth for the Iwollo site was 90.9 and 117.9 Mg ha-1, respectively, for the 2013 and 2014 planting season in No-till plots where 300 Kg ha^{-1} of NPK was applied. This was followed by No-tilled plots treated with 150 Kg ha^{-1} of NPK, which sequestered 86.2 and 91.9 Mg ha-1 organic carbon. Conventionally-tilled plots that received 300 Kg ha-1 NPK with 47.6 Mg ha^{-1} organic carbon had 44 % and 28 % lower stored organic carbon content when compared to No-till, NPK 150 Kg ha^{-1} plots for 2013 and 2014 planting season respectively. These results showed that No-till plots had significantly higher post-harvest sequestered organic carbon content when compared to conventionally tilled plots at 0-20cm soil depth. At the Agbani site, the results followed the same trend. No-tilled plots at 0-20cm depth had sequestered 46.7 and 65.0 Mg ha^{-1} of organic carbon for 2013 and 2014 planting season respectively for plots treated with 300 Kg ha^{-1} of NPK.

Conventionally-tilled plots that received 300 Kg ha^{-1} NPK with 11.5 Mg ha^{-1} organic carbon had 72 % and 41 % lower stored organic carbon content when compared to No-till, NPK 150 Kg ha^{-1} plots for 2013 and 2014 planting season respectively. At 20-40 cm soil depth, No-tilled plots that were fertilized with 300 and 150 Kg ha^{-1} NPK 15:15:15 with 165 - 184.8 Mg ha^{-1} and 152.6 -173.2 Mg ha^{-1} stored organic carbon had 49 - 64 % more stored organic carbon content relative to CT plots where 300 and 150 Kg ha-1 NPK was applied in the 2013 and 2014 planting season respectively at the Iwollo site. The results followed the same trend at the Agbani site.

4.0. Discussion

4.1 Soil properties

Table 1: Soil properties of the study sites collected at 0–30 cm depth at the onset of the experiment

PRE-PLANTING ANALYSIS	IWOLLO	AGBANI
Clay (%)	19 (0.91)	8 (0.98)
Silt (%)	15 (0.18)	7 (0.23)
Sand (%)	66 (1.18)	85 (0.91)
pH (H_20)	6.0 (0.78)	6.4 (0.51)
pH (KCl)	5.2 (0.14)	5.5 (0.34)
Organic Carbon (%)	1.68 (0.43)	1.08 (0.80)
Organic Matter (%)	2.90 (0.48)	1.86 (0.38)
N (%)	0.126 (0.35)	0.056 (0.27)
Na^+ ($Cmolkg^{-1}$)	0.15 (0.52)	0.09 (0.50)
K ($Cmolkg^{-1}$)	0.10 (0.28)	0.06 (0.34)
Ca ($Cmolkg^{-1}$)	3.80 (0.45)	4.2 (0.57)
Mg ($Cmolkg^{-1}$)	2.20 (0.35)	1.2 (0.21)
CEC ($Cmolkg^{-1}$)	23.20 (0.67)	8.4 (0.08)
AL ($Cmolkg^{-1}$)	0.40 (0.72)	0.27 (0.31)
Ex. Acidity ($Cmolkg^{-1}$)	1.80 (0.28)	0.60 (0.13)
Available P($Cmolkg^{-1}$)	7.46 (0.91)	15.64 (0.18)
Bulk density (Mgm^{-3})	1.52 (0.48)	1.46 (0.46)
Total Porosity (g/cm^3)	39.25 (0.41)	46.04 (0.21)
Hydraulic conductivity (Kcm^3/hr)	30.30 (0.16)	21.72 (0.18)

Figures in parentheses are standard deviations

The variation in the microenvironment (ecology) and management of the sites probably resulted in the differences in soil properties and, therefore, soil organic carbon stocks of the different sites since the soils were Paleustults formed in the same geographic zone. This implies that differences in soil management practices may have directly impacted the differences in carbon stocks. Anikwe (2010) showed that soils at different sites always differ in properties and fertility, texture and structures but even if they are the same, certain factors such as continuous tillage (cultivation), climate, soil amendments, and other farming activities and management could have made them differ in texture and structure which in turn will affect the growth characteristics and yield indices of crops, fertility or nutrient status of the soil.

Table 2: Effect of tillage and NPK fertilization rates on carbon sequestration (Mg ha^{-1}) at different soil depths in the Iwollo and Agbani sites during 2013 and 2014 cropping seasons

	IWOLLO SITE				AGBANI SITE			
	0 -20 cm		21 - 40 cm		0 -20 cm		21 - 40 cm	
Treatments	2013	2014	2013	2014	2013	2014	2013	2014
CT 150	48.50	64.70	62.40	78.50	8.80	26.70	6.50	4.50
CT300	47.60	66.60	91.80	82.80	11.50	32.80	11.40	53.20
NT150	86.20	91.90	173.20	152.60	42.40	55.50	46.70	62.20
NT300	90.90	117.90	184.80	165.00	46.70	65.00	54.50	121.80
F-LSD(0.05)	0.40	2.20	3.20	1.30	1.60	1.40	3.20	6.40

CT 150 and 300 = Conventional Tillage with 150 and 300kg of NPK 15:15:15

NT 150 and 300 = No-Tillage with 150 and 300 kg of NPK 15:15:15

4.2. Effect of tillage practices on soil organic carbon sequestration

The results showed that a statistically higher quantity of sequestered organic carbon was found at No-till when compared with conventionally tilled sites. Similarly, a lesser amount of sequestered soil organic carbon was found in 0-20 cm soil depths when compared with 20-40 cm soil depths for the two sites. This indicates that conventional tillage techniques significantly limit soil organic carbon (SOC) storage. Shrestha et al. (2015) observed that land management and cropping systems influence the quantity and quality of soil organic carbon stock and, therefore, constitute a driving force for soil organic carbon storage. They reported that no tillage system indicated significantly larger SOC sequestration than the CT system at the 0–10 cm depth after the 26 years of their experiment, but it was not significantly different at the 10–30 cm depth. In terms of quality, SOM was found to differ by the rate of fertilizer application, crop rotation, and tillage type.

The results from this work implied that more of the C in both conventional and No-tilled plots are found at the lower, 20-40 cm when compared to the 0-20cm soil depth. From the results above, it was observed that soil organic carbon (SOC) increased in lower topsoil than in the upper topsoil layers in these degraded Ultisols. This may be because of continuous cultivation on the topsoil as traditional hoes, which is primarily used as tillage equipment seldom dig past the upper soil layer (20-30 cm); hence, only the upper soil layer (0-20 cm) is continuously mixed and disturbed. Soil organic carbon sequestered as SOC is regulated by the soil ecology and the quality of the soil organic matter in which the carbon resides. Sequestering C within the soil organic matter (SOM) is among the best options for C storage in terrestrial ecosystems. Besides helping offset CO_2 emissions into Earth's atmosphere, C sequestration into SOM provides multiple benefits, such as improved soil quality through enhanced fertility, soil structure and aggregate stability, water holding capacity, and the capacity to reduce toxic elements.

Conventional-tillage with 300 Kg of NPK 15:15:15 had the highest corm yield, followed by No-till with 300 Kg ha^{-1}, Conventional-till with 150 Kg ha^{-1}, and lastly No-till with 150 Kg ha^{-1}. No significant differences in corm yield were found between conventionally-tilled plots with 300 and 150 Kg ha^{-1} N and between No-tilled plots with 300 and 150 Kg ha^{-1} N at both sites (Table 3).

This means that better edaphic conditions provided by conventional tillage were compensated for by higher doses of N fertilizer. Results from this work indicated that in places where No-till is preferable to reduce costs and adverse effects of continuous tillage on soil properties, fertilizer application could be used to increase yield and to compensate for the adverse impact of No-till on crop yield temporarily. Tieszen (2000) postulated that farming and other land use systems have a significant effect on the quantity of carbon that can be stored and how long it can be stored in the soil before it is returned to its atmospheric state. The essential approaches centre on the saving of soil organic carbon against further erosion and, consequently, depletion and, or the use of management practices to restore depleted carbon stocks. However, an essential objective of successful soil carbon sequestration is increased plant growth, productivity, increased net primary production, and reduced decomposition.

Table 3: Effect of tillage and N fertilization rates on yield (t ha^{-1}) of cocoyam at harvest (210 DAP) during 2013 and 2014 planting season in Iwollo and Agbani sites

	IWOLLO SITE		**AGBANI SITE**	
Treatment	2013	2014	2013	2014
CT150	6.46	5.95	6.26	5.81
CT300	8.58	7.83	8.16	7.72
NT150	5.54	4.98	4.92	4.19
NT300	6.58	6.00	5.7	5.30
F-LSD (0.05)	2.8	2.06	1.2	0.65

CT 150 and 300 = Convention tillage with 150 and 300 kg of NPK 15:15:15

NT 150 and 300 = No tillage with 150 and 300 kg of NPK 15:15:15

F-LSD = Fisher's Least Significant Difference.

5.0. Conclusions

The results of this study showed that at the Iwollo site, conventional tillage and no-till plots amended with varying rates of NPK fertilization significantly enhanced soil organic carbon reserves at the lower soil depth (20-40 cm) when compared to the 0-20 cm soil layer. The results also showed that a statistically higher quantity of sequestered organic carbon was found at No-till when compared with conventionally tilled sites. Similarly, a lesser quantity of sequestered soil organic carbon was found in 0-20cm soil depths when compared with 20-40cm soil depths for all sites. This indicates that conventional tillage practices significantly limits soil organic carbon (SOC) sequestration. Quantification of soil carbon (C) cycling as affected by management practices is needed for C sequestration and soil quality improvement. No-till soil management practices can store organic carbon, offset atmospheric CO2 concentrations, and ameliorate soil and ecosystem quality on a short-term basis when compared to conventional tillage. The results also showed that tillage practices and N fertilization rates significantly (P=0.05) affected yield indices of cocoyam. Conventional-tillage with 300 Kg of NPK 15:15:15 had the highest corm yield, followed by No-till with 300 Kg ha^{-1}, Conventional-till with 150 Kg ha^{-1}, and lastly No-till with 150 Kg/ha. This means that conventional till with 300 Kg/ha^{-1} provided a superior edaphic environment for the crop when compared to other treatments used in the study. A better edaphic condition provided by conventional tillage was compensated for by higher doses of N fertilizer in NT Plots.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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