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CHANGES IN WATER STABLE SOIL AGGREGATES OF A TYPIC HAPLUSTULTS UNDER DIFFERENT TILLAGE PRACTICES AND COVER CROPS

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Abstract

Tillage influences soil organic matter content and in turn stability of soil aggregates. Soil aggregation is paramount to crop growth, nutrient transport and gaseous exchange. This study investigated the effect of tillage practices and cover crops on water stable aggregates in the plough layer of a Typic Haplustults. Field trials were conducted for three years at the Institute for Agricultural Research farm, Zaria, Nigeria. The field was laid out in a randomized complete block design, split plot arrangement and replicated three times, with three tillage practices [no-till (NT), reduced till (RT) and conventional till (CT)] as main treatment and five cover crops (Glycine max, Centrosema pascuorum, Macrotyloma uniflorum, Cucurbita maxima and a control (bare, with no sown cover crop)) as sub treatment. After harvest of test crop each year, soil samples were collected from depths 0-5, 5-10, 10-15 and 15-20 cm. The samples were subjected to wet sieving by slaking and the extent of aggregation was determined by mean weight diameter (MWD) and geometric mean diameter. Conservation management practices such as NT, RT and cover cropping improved water stable macro aggregation and consequently aggregate stability relative to the CT and in management practice without cover crop. Geometric mean diameter indicated that NT had 15% and 31% more water stable aggregate than the RT and CT soils respectively. Soils under cover crops had 14% better aggregate stability than the bare soil while MWD indicated surface soil (0-5 cm) were 13% more stable than soils from other sampling depths (5-10, 10-15 and 15-20 cm), suggesting that conservation till (NT and RT) and cover crops are important drivers of soil ecosystem functions.

Keywords: cover crop, tillage, water stable aggregate

Introduction

Soil aggregate is a group of primary soil particles bound to each other more strongly than the neighbouring particles, while aggregate stability is the resistance as offered by soil aggregates against the external force applied for disruption (Singh *et* al., 2017). Soil structural quality depends on the stability of aggregates, which affect many physical and biogeochemical processes in terrestrial ecosystems (Ayoubi *et al*., 2020; Zeeratpisheh *et al.,* 2021). Therefore, it is essential to maintain good soil structure as it constitutes the habitat for a myriad of soil organisms, consequently driving their diversity and regulating their activity (Elliott and Coleman, 1988). Soil aggregation is linked to many processes in soils. It is important for crop establishment as it regulates water retention and infiltration, gaseous exchanges, soil organic matter and nutrient dynamics, root penetration, and susceptibility to erosion and compaction. Hence the measurement of aggregate stability is crucial in understanding the erosive and crusting potential of soils (Amézketa 1999). Aggregate stability is an important characteristic of soil sustainability and productivity because formation of soil aggregates may be affected directly or indirectly by management practices or by the biotic and abiotic factors that determine the soil fertility and sustainability (Besalatpour *et al.*, 2013; Besalatpour *et al.*, 2014). Deterioration of soil quality results in changes in structure and function of soil, which in turn, exert influence on ecosystem structure and function.

Soils of the savanna are generally weakly aggregated, with high bulk density, low organic matter content and poor buffering capacity (Lawal, 2020). Furthermore, continuous yearly soil cultivation under the conventional tillage, generally practiced in Nigeria is exploitive and causes a decline in soil organic matter content due to shearing of soil aggregates by tillage implements (Lawal, 2022). This decline is aggravated where crop residues are removed as practiced in northern Nigeria, either for the crop residues to be fed to animals or used as fencing materials. Consequently, exposing soil aggregates to frequent physical disruption by rapid wetting from raindrop impact, due to partial or lack of vegetative cover before crop reaches full canopy cover. The net effect of these limited vegetal cover is accelerated soil erosion and exposure of inaccessible organic matter to microorganisms thereby stimulating oxidation and loss of organic matter (nutrient depletion) which is detrimental to soil productivity and sustainable agricultural development (Wegner *et al.*, 2018).

Long-term sustainable soil management has become a major global challenge of this century, however, one challenge faced in northern Nigeria is in finding an alternative to the continuous conventional tillage system. Conservation tillage which leaves more than 15% residues cover on soil surface such as no-till and reduced till, and other sustainable organic matter generating management practices such as cover cropping, will be a candid alternative to the conventional tillage system, to take care of the peculiar low organic matter nature of soils of northern Nigeria. In addition, appropriate cover crop for conservation tillage for this biome remains to be determined. This study therefore aimed at evaluating the effects of tillage and cover crops on the distribution and stability of water stable aggregate within the plough layer.

Materials and Methods

Description of Experimental Site

The study site is the Institute for Agricultural Research Farm, Samaru, (11°10.416'N, 07°37.812'E, 700 m above sea level) in the Northern Guinea Savanna ecological zone of Nigeria. The soil type is Typic Haplusults (USDA Soil Taxonomy), derived from pre-Cambrian crystalline basement complex rocks with some quaternary aeolian deposits. The field had been on fallow for 18years before the trials commenced in 2011. The surface soil (0-15 cm) is loam (L) in texture with an average of 43% sand, 43% silt and 14% clay and moderately acidic in soil reaction (pH 5.4 in $CaCl_2$), with moderate organic carbon (10.17 g kg^{-1}) and bulk density (1.4 Mg m^{-3}); but poor in total nitrogen (0.72 g kg^{-1}). The soil has very low available phosphorus (2.56 mg kg^{-1}), and cation exchange capacity (4.3 cmol kg^{-1}). The topography is almost plain (nearly levelled) with < 2% slope. Samaru is characterized by a mono modal rainfall pattern with a long term mean annual rainfall of about 1,011 ± 161 mm, which spreads from March/April to October with the highest concentration in July to September. Samaru has long-term mean minimum and maximum temperatures of 21.1^0C and 33.5^0C respectively and relative humidity of 55.23%.

Experimental Design and Treatments

The experiment was laid out in a randomized complete block design, split plot arrangement and replicated three times. Tillage practices and cover crops were allocated to the main and subplots respectively. Tillage operations were carried out using a tractor-drawn disc plough, disc harrow and disc ridger as per treatment requirement. The experimental field was cropped to Maize (*Zea mays*) as the test crop for three rainy seasons (2011-2013). The treatments consisted of three tillage practices as follows: No - tillage (NT), this involved no soil disturbance except opening sowing holes and crop residues were left on soil surface; Reduced tillage (RT), here fields were harrowed once and crops planted, with crop residue incorporated, and the Conventional tillage (CT), which involved ploughing, harrowing and ridging with crop residue removed as practiced by local farmers in northern Nigeria. And four cover crops namely: *Centrosema pascuorum, Macrotyloma uniflorum, Glycine max, Cucurbita maxima* and a control or check with no cover crop (bare).

Cultural Practices

At two weeks prior to land preparation, the whole experimental field was sprayed with herbicide (Glyphosate), at the rate of 3 litres per hectare irrespective of the type of tillage operation adopted. Furthermore, pedimenthalin, a pre-emergence herbicide was applied immediately after sowing of cover crops, at a rate of 1 litre per hectare. The seeds of maize and the cover crops were treated with Apron star (methylthiuram + metalaxyl + carboxin) at the rate of 3 kg seeds per 10 g sachet of the agro-chemical. Inorganic fertilizer was applied at the rate of 120 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} to the maize crop, nitrogen was however applied in two equal split doses (at 2 and 6weeks after sowing (WAS) maize seed). Half of the N and all of the P and K were applied using NPK (15:15:15) at 2 WAS while the second dose of N was applied using urea at 6 WAS by side dressing. Weeding was done at 6 WAS manually, using traditional hoes in the conventional and reduced tillage treatments while weeds in the no-till treatment were controlled by hand pulling. Weeds cut in both no-till and reduced tillage plots were left on the soil surfaces while those cut from conventionally tilled plots were removed from the field as practiced by conventional farmers. Earthen up was done at 10 WAS maize in the conventional tillage system.

Soil Sampling

After harvest of test crop at the end of the cropping season each year, in each replication, composite soil samples were taken from each treatment plots at depths 0-5, 5-10, 10-15 and 15-20 cm, with the aid of an auger.

Water Stable Aggregate Fractionation

Soil aggregate stability was determined by physical fractionation employing the wet sieving technique (Elliot, 1986). A 200 g of 5 mm sieved sample was wetted by rapid immersion in water and sieved with a number of 50, 30, and 10 strokes per minutes through sieve sizes of 2 mm, 0.25 mm and 0.053 mm respectively, for two minutes each. The sieving was carried out in order of decreasing mesh size. After sieving, with the initial sieve (2 mm) the residue was transferred onto the successive sieve (0.25 mm), and then onto 0.053 mm sieve. The < 0.053 mm aggregate fraction was allowed to settle down before its water was decanted. The fractionated aggregates were oven dried at 60ºC until a constant weight was achieved. The proportion of each aggregate fraction > 0.053 mm was corrected for sand as described by Masri and Ryan (2006). Stability of the water stable soil aggregates was determined by mean weight diameter (MWD) and the Geometric mean diameter (GMD).

The proportional weight of sand free aggregates is given as:

$$\frac{\text{Weight of aggregate fraction} - \text{\% sand content in the aggregate fraction}}{\text{Weight of bulk soil} - \text{\% sand content in the bulk soil}} \quad \text{(Masri and Ryan, 2006)}$$

$$\text{MWD} = \sum_{i=1}^{n} xi\ wi$$

xi = mean diameter of two successive sieves, Wi = proportional weight of sand free aggregates

$$\text{Geometric mean diameter (GMD)} = \exp\left[\frac{\sum_{i=1}^{n} wi \log xi}{\sum_{i=1}^{n} wi}\right]$$

wi = weight of sand free aggregate in a size class with an average diameter, xi

$\sum_{i=1}^{n}$ = total weight of the sample.

Data Analysis

All data collected for the three years of study were subjected to statistical analysis of variance for randomized complete block design, using the generalized linear model (GLM) procedure of statistical analytical software, SAS package (SAS, 2009) Significant difference among treatment means ($p \leq 0.05$) were separated using the Duncan multiple range test of the same software package.

Results

Effect of Tillage Cover Crop and Sampling Depth on Water Stable Aggregate

The effect of tillage, cover crop and sampling depth on water stable soil aggregate during the 2011 cropping season is presented in Table 1. Tillage did not significantly influence proportional weight of large macroaggregate (5-2 mm). However, conservation tillage systems (NT and RT) had significantly ($p \leq 0.01$) more stable small macroaggregate (2-0.25 mm) fraction, as well as MWD and Geometric Mean Diameter, (GMD) relative to the CT system. The proportion of microaggregate (0.25 -0.053mm) and silt plus clay (< 0.053 mm) fractions, were significantly ($p \leq 0.05$) higher in both RT and CT relative to the NT soil. Cover crops evaluated in this study did not significantly influence proportional weight of all the fractions of water stable aggregates and their MWD. However, significant ($p \leq 0.05$) difference was observed in the GMD, where soils under any of the evaluated cover crop had significantly ($p \leq 0.05$) better soil aggregate stability relative to the bare plots with no cover crop. Furthermore, higher proportion of both large and small water stable macro aggregate concentrated more ($p \leq 0.01$) at the surface (0-5 cm) soil relative to other sampling depth, while significantly ($p \leq 0.05$) lowest proportion of microaggregates were found in 0-5 cm depth. Significantly ($p \leq 0.01$) higher aggregate stability as indicated by the MWD and GMD were observed at 0-5 cm depth relative to the other sampling depths.

Table 1: Tillage, Cover Crop and Sampling Depth Effects on Water Stable Soil Aggregate during the 2011 Cropping Season at Samaru, Nigeria

	← Sizes of soil aggregates fraction →				(mm)	
Treatments	5-2 mm	2- 0.25 mm	0.25 - 0.053 mm	<0.053 mm	MWD	GMD
Tillage (T)	← proportional weight of soil aggregates →					
No till (NT)	0.0232	0.2952^{a}	0.3910^{b}	0.2326^{c}	0.4718^{a}	0.5024^{a}
Reduced (RT)	0.0221	0.2508^{a}	0.4509^{a}	0.2742^{b}	0.4372^{b}	0.4485^{b}
Conventional (CT)	0.0111	0.2061^{b}	0.4220^{a}	0.3633^{a}	0.3433^{c}	0.3952^{c}
SE ±	0.04111	0.00342	0.00691	0.00129	0.00562	0.00235
Significance	NS	**	**	*	**	**
Cover Crops (C.)						
No Cover	0.0228	0.2471	0.4090	0.2129	0.4261	0.4314^{b}
Macrotyloma uniflorum	0.0239	0.2511	0.4261	0.2125	0.4370	0.4487^{a}
Centrosema pascorum	0.0258	0.2452	0.4261	0.2127	0.4370	0.4482^{a}
Glycine max	0.0242	0.2522	0.4261	0.2125	0.4394	0.4487^{a}
Cucurbita maxima	0.0264	0.2483	0.4072	0.2128	0.4398	0.4485^{a}
SE ±	0.00525	0.00438	0.00904	0.000167	0.00731	0.00303
Significance	NS	NS	NS	NS	NS	*
Depth (cm) D						
0-5	0.0131^{a}	0.2646^{a}	0.398^{c}	0.2125	0.418^{a}	0.4168^{a}
5-10	0.0072^{b}	0.2516^{b}	0.411^{bc}	0.2128	0.3781^{b}	0.383^{b}
10-15	0.0064^{b}	0.2375^{c}	0.428^{ab}	0.2129	0.3577^{c}	0.3772^{b}
15-20	0.0065^{b}	0.2403^{c}	0.438^{a}	0.2126	0.3625^{bc}	0.381^{b}
SE ±	0.00470	0.00393	0.00081	0.00149	0.00653	0.00271
Significance	**	**	**	NS	**	**
Interactions						
T x C	NS	NS	NS	NS	NS	NS
T x D	NS	NS	NS	NS	NS	NS
D x C	NS	NS	NS	NS	NS	NS
T x D x C	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Duncan Multiple Range Test. SE = standard error, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, NS = not significant

The effect of tillage, cover crop and sampling depth on water stable soil aggregate during the 2012 cropping season is presented in Table 2. Tillage did not significantly influence proportional weight of large macroaggregates (5-2 mm) fraction. However, it was revealed that soils under NT and RT practices had significantly ($p \leq 0.01$) higher proportion of small macroaggregates than soil under CT practice. Meanwhile, the microaggregate and silt plus clay fractions were significantly ($p \leq 0.01$) higher in CT treatment plot, than NT. Variation due to tillage revealed stability of soil aggregates was in the order of NT > RT > CT as indicated by both MWD and GMD. The growing of cover crops did not have any significant effect on large macroaggregate and microaggregate fractions, however, all evaluated cover crops significantly ($p \leq 0.01$) influenced higher proportion of small macroaggregate relative to the bare plots with no cover crop while silt plus clay fraction were lower in plots with cover crops However, MWD and GMD indicated that cover cropped plots presented a better water stable aggregate than the bare plots. Large and small macro aggregate proportion were not significantly influenced by soil depth. Variation in the sampling depth showed significant ($p \leq 0.01$) decrease in microaggregate and increase in silt plus clay fraction with sampling depth. Furthermore, MWD and GMD were significantly ($p \leq 0.01$) enhanced at the soil surface (0-5 cm) relative to all other depths.

Table 2: Tillage, Cover Crop And Sampling Depth Effects On Water Stable Soil Aggregate During The 2012 Cropping Season At Samaru, Nigeria

	← Sizes of soil aggregates fraction →				(mm)	
Treatments	5 -2 mm	2 -0.25 mm	0.25-0.053 mm	<0.053 mm	MWD	GMD
Tillage (T)	← proportional weight of soil aggregates →					
No till (NT)	0.0233	0.2950^{a}	0.3908^{b}	0.2323^{c}	0.4720^{a}	0.5026^{a}
Reduced (RT)	0.0220	0.2561^{a}	0.4512^{a}	0.2742^{b}	0.4371^{b}	0.4490^{b}
Conventional (CT)	0.0109	0.2059^{b}	0.4224^{a}	0.3650^{a}	0.3433^{c}	0.3958^{c}
SE ±	0.001831	0.002053	0.004235	0.004965	0.005997	0.001949
Significance	NS	**	**	**	*	*
Cover Crops (C.)						
No Cover	0.0238	0.1896^{b}	0.2151	0.5675^{a}	0.3451^{b}	0.3518^{b}
Macrotyloma uniflorum	0.0264	0.2911^{a}	0.2412	0.4373^{b}	0.4693^{a}	0.4253^{a}
Centrosema pascorum	0.0284	0.2799^{a}	0.2195	0.4684^{b}	0.4612^{a}	0.4125^{a}
Glycine max	0.0243	0.2898^{a}	0.2292	0.4528^{b}	0.4591^{a}	0.4187^{a}
Cucurbita maxima	0.0271	0.2777^{a}	0.2369	0.4543^{b}	0.4565^{a}	0.4154^{a}
SE ±	0.002364	0.002649	0.005468	0.006409	0.007742	0.002517
Significance	NS	**	NS	**	**	**
Depth (cm) D						
0-5	0.0246	0.2187	0.4559^{a}	0.2963^{b}	0.4096^{a}	0.4424^{a}
5 -10	0.0221	0.1913	0.2341^{b}	0.5488^{a}	0.3434^{b}	0.3554^{b}
10 -15	0.0219	0.1875	0.226^{b}	0.5605^{a}	0.3366^{b}	0.3521^{b}
15-20	0.0223	0.1673	0.2238^{b}	0.5627^{a}	0.3546^{b}	0.3512^{b}
SE ±	0.002114	0.002371	0.004891	0.005733	0.006924	0.002251
Significance	NS	NS	**	**	**	**
Interactions						
T x C	NS	NS	NS	NS	NS	NS
T x D	NS	NS	NS	NS	NS	NS
D x C	NS	NS	NS	NS	NS	NS
T x D x C	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Duncan Multiple Range Test. SE = standard error, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, NS = not significant

The effect of tillage, cover crop and soil sampling depth on water stable soil aggregate in 2013 is presented in Table 3. Significant ($p \leq 0.05$) effect was observed among the different tillage practices adopted for proportional weights of all aggregate fractions and the two indices (MWD, GMD) used to characterize their stability.

Table 3: Tillage, Cover Crop and Sampling Depth Effects on Water Stable Soil Aggregate During the 2013 Cropping Season at Samaru, Northern Nigeria

	← Sizes of soil aggregates fraction →				(mm)	
Treatments	5- 2 mm	2 - 0.25 mm	0.25- 0.053 mm	<0.053mm	MWD	GMD
Tillage (T)	← Proportional weight of soil aggregates →					
No till (NT)	0.0519a	0.3151^{a}	0.2952^{c}	0.2771^{b}	0.5894^{a}	0.5309^{a}
Reduced (RT)	0.0318b	0.2175^{b}	0.4085^{a}	0.3310^{a}	0.4272^{b}	0.4373^{b}
Conventional (CT)	0.0114c	0.1615^{c}	0.4417^{b}	0.3849^{a}	0.2990^{c}	0.3855^{c}
SE ±	0.00296	0.00225	0.00248	0.00278	0.00473	0.00188
Significance	**	**	*	*	*	*
Cover Crops (C.)						
No Cover	0.0203^{b}	0.1882	0.1521	0.3402^{a}	0.3157^{b}	0.5283^{b}
Macrotyloma uniflorum	0.0502^{a}	0.2207	0.1419	0.2749^{b}	0.4538^{a}	0.6009^{a}
Centrosema pascorum	0.0471^{a}	0.2125	0.1311	0.2906^{b}	0.4325^{a}	0.5904^{a}
Glycine max	0.0492^{a}	0.2208	0.1358	0.2826^{b}	0.4497^{a}	0.5964^{a}
Cucurbita maxima	0.0468^{a}	0.2123	0.1338	0.2835^{b}	0.4314^{a}	0.5955^{a}
SE ±	0.00383	0.00290	0.00320	0.00360	0.00611	0.00242
Significance	**	NS	NS	**	**	*
Depth (cm) D						
0-5	0.0511^{b}	0.2305^{a}	0.1347	0.2824	0.4671	0.5981
5-10	0.0472^{c}	0.2214^{b}	0.1376	0.2807	0.4436	0.5967
10-15	0.0428^{d}	0.2125^{c}	0.1344	0.2866	0.4178	0.5912
15-20	0.0536^{a}	0.2038^{d}	0.1338	0.2876	0.4457	0.5936
SE ±	0.00342	0.00259	0.00287	0.00322	0.00546	0.00217
Significance	*	**	NS	NS	NS	NS
Interactions						
T x C	NS	NS	NS	NS	NS	NS
T x D	NS	NS	NS	NS	NS	NS
D x C	NS	NS	NS	NS	NS	NS
T x D x C	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Duncan Multiple Range Test. SE = standard error, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$ and NS = not significant

Soil under NT had significantly ($p \leq 0.01$) higher large and small macro aggregate fractions, it was followed by the RT then the conventionally tilled soil. However, soils under NT practice had significantly ($p \leq 0.05$) lower stability of microaggregate and silt plus clay fraction (< 0.053 mm) relative to the RT and CT whose microaggregate and silt plus clay fraction were significantly ($p \leq 0.05$) more stable as indicated by the higher proportion of these soil fraction. Both MWD and GMD showed the stability of the water stable aggregates as affected by tillage were in the order of NT > RT > CT. All soils under any of the different cover crop evaluated, significantly ($p \leq 0.05$) influence the proportional weight of large macroaggregates, MWD and GMD better than the bare soil with no cover crop. Both small macroaggregate and microaggregate fractions were not significantly influenced by cover crop while all plots under any of evaluated cover crop had significantly lower silt plus clay soil fraction relative to the no cover crop plot.

Variation in the sampling depth indicated a significant ($p \leq 0.05$) influence in both large and small soil macro aggregate fractions (5-2 mm and 2 - 0.25 mm). The lowest sampling depth evaluated (15-20 cm) had highest proportion of large macro aggregate, it was followed by depth 0-5 cm, then depth 5-10 cm while depth 10-15 cm had least stable large macro aggregate. There was a significant ($p \leq 0.01$) decrease in small macro aggregate stability with increase in sampling depth. However, no significant effect of sampling depth was observed in microaggregate, silt plus clay fraction, MWD and GMD.

The effect of tillage cover crop and sampling depth on water stable soil aggregate combined across the three years (2011, 2012 and 2013) of experimentation is presented in Table 4. Large and small macro aggregates, MWD and GMD were significantly ($p \leq 0.05$) influenced in the order of NT > RT > CT. Geometric mean diameter indicated that NT had 15 % and 31 % more water stable aggregate than the RT and CT soils, respectively. The proportional weights of microaggregate were not significantly influenced by the tillage practices implored. However, RT and CT treatments plots had significantly ($p \leq 0.01$) more stable silt plus clay aggregate fraction relative to soils under NT treatment. Variations in the cover crops did not significantly influence the proportional weights of all aggregate fractions except the silt plus clay soil fraction, where significantly ($p \leq 0.05$) lower proportion of this fraction was observed in all soils under any of evaluated cover crops relative to the bare (no cover crop) plots. However, results from MWD and GMD indicated significantly ($p \leq 0.01$) better water stable aggregate in all cover crop plots than the bare soil with no cover crop. Geometric mean

Table 4: Tillage Cover Crop and Sampling Depth Effects on Water Stable Soil Aggregate Combined across the three Years (2011, 2012 And 2013) at Samaru, Northern Nigeria

	← Sizes of soil aggregates fraction →				(mm)	
Treatments	5- 2 mm	2 - 0.25 mm	0.25- 0.053 mm	<0.053mm	MWD	GMD
Tillage (T)	← Proportional weight of soil aggregates →					
No till (NT)	0.0328a	0.3018a	0.3591	0.2474c	0.5110a	0.5119a
Reduced (RT)	0.0253ab	0.2421b	0.4368	0.2931b	0.4339ab	0.4448b
Conventional (CT)	0.0112c	0.1912c	0.4286	0.3501a	0.3285b	0.3919c
SE ±	0.00482	0.01180	0.01927	0.00595	0.02843	0.00750
Significance	*	**	NS	**	*	**
Cover Crops (C.)						
No Cover	0.0223	0.2083	0.2587	0.3735a	0.3623b	0.4372b
Macrotyloma uniflorum	0.0335	0.2543	0.2697	0.3082b	0.4533a	0.4916a
Centrosema pascorum	0.0338	0.2459	0.2589	0.3239b	0.4436a	0.4837a
Glycine max	0.0326	0.2543	0.2637	0.3160b	0.4494a	0.4879a
Cucurbita maxima	0.0334	0.2461	0.2593	0.3169b	0.4435a	0.4864a
SE ±	0.00391	0.01242	0.00610	0.01506	0.01665	0.00755
Significance	NS	NS	NS	NS	*	**
Depth (cm) D						
0-5	0.0296	0.2379a	0.3295	0.2637	0.4315a	0.4857
5-10	0.0255	0.2214b	0.2609	0.3474	0.3884b	0.4450
10-15	0.0237	0.2125bc	0.2628	0.3533	0.3707b	0.4401
15-20	0.0274	0.2038c	0.2652	0.3543	0.3876b	0.4419
SE ±	0.00157	0.00395	0.04081	0.04331	0.00624	0.01244
Significance	NS	**	NS	NS	**	NS
Interactions						
T x C	NS	NS	NS	NS	NS	NS
T x D	NS	NS	NS	NS	NS	NS
D x C	NS	NS	NS	NS	NS	NS
T x D x C	NS	NS	NS	NS	NS	NS

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of significance using Duncan Multiple Range Test. SE = standard error, * = Significant at $p \leq 0.05$, ** = Significant at $p \leq 0.01$, NS = not significant.

diameter revealed that soils under any of cover crops on the average had 14 % better aggregate stability than the bare soil (NC).

Variation in the sampling depth indicated no significant influence on the proportional weight of all aggregate fractions and GMD except the small soil macro aggregate fractions (2 - 0.25 mm), which showed a significant ($p \leq 0.01$) decrease in small macro aggregate stability with increase in sampling depth. However, MWD revealed that the surface soil (0-5 cm) had significantly ($p \leq 0.01$) higher (13% more) aggregate stability than all other depths.

Discussion

The least proportion of water stable macroaggregate fraction (>0.25 mm) in CT relative to NT and RT soils, could be attributed to the disruption of macroaggregate due to shattering effect of tillage implements on soil aggregates, during ploughing and harrowing operations as it is done in CT practice. This disruption results in the oxidation of previously protected soil organic carbon which stabilizes soil aggregate (Ayuobi *et* al., 2020; Srinivasan *et al*., 2012). This finding lends credence to the work of Six *et al*. (2000), who proposed that mechanical disturbances disrupt macroaggregates and reduce soil structural stability. Furthermore, high levels of surface residue, year-round diverse vegetation, and little physical soil disturbance in conservation tillage systems; encourages the abundance, activity, and diversity of soil organisms especially, earthworms and fungi (Lawal, 2020), consequently, improving soil aggregate stability and structure (González *et al.,* 2017).

Lawal (2020), reported higher fungal colony forming units (CFU) in NT (1.70×10^6) soils of this study area as against RT (6.50×10^5) and CT (1.30×10^6) tillage systems, which were 162% and 31% higher in NT than RT and CT respectively. This high fungal CFU in NT soil could give room for plant root hairs and fungal hyphae to exude sugar like polysaccharides and other organic compounds (Weil and Brady, 2017) thus, forming sticky networks that binds individual soil particles and tiny microaggregates together into larger agglomerations called macroaggregates, and in so doing, improve soil aggregate stability. Additionally, the high population of fungi in NT could promote the presence of mucigel which is rich in polysaccharide content (Gałązka *et al*., 2020), thereby stabilizing soil aggregates and improving the physical conditions for both root and microbial growth (Gałązka *et al*., 2020).

It is also possible that the presence of thread like fungi that associate with plant roots (mycorrhizae) were effective in providing stabilization for water stable macroaggregate as they secrete a gooey protein called glomalin (Gałązka *et al*., 2020), which is an effective cementing agent for soil aggregates (Weil and Brady, 2017) as they slough off the hyphae of fungi. The combine strength of mycorrhizae hyphae and fine roots, binds particles equally in all directions (Weil and Brady, 2017), ensuring that aggregates do not slake when wetted rapidly. Glomalin related soil protein had been reported by Gillespie *et al.* (2011) and Gałązka *et al*., (2018) to significantly aid the formation of stable soil aggregates, as it facilitates adhesion of mineral particles. This protein covers the surface of soil particles, creating a characteristic, protective coating that strengthen the stability of soil aggregates (Gałązka *et al*., 2020).

In all plots on which cover crops were planted, higher root concentration and organic matter deposition, as a result of higher biomass production and subsequent return of biomass to soil, may be responsible for better soil aggregate stability on these plots than that obtained in the bare (control) plots. Fresh residues from overlying cover crops on treated plots, could serve as nucleation sites for fungal and other soil microbial growth (West and Post, 2002). Since, fresh organic residues are rich in fine particulate organic matter which primarily serve as nucleation site for macroaggregate formation (Denef *et al*., 2004). Wegner *et al.* (2018), observed that cover cropping increased fine particulate organic matter levels, soil microbial enzyme activities and fungal bacterial ratios; therefore, reduced the erodible fraction of soil aggregates and increased the stable, larger aggregate fractions, in spite of corn residue removal.

Roots of cover crops could stimulate soil microbial activity and contribute to the abundance of arbuscular mycorrhizal fungi (Gałązka *et al*., 2018; Scheublin, 2004), which have positive effects on soil aggregate stability. Furthermore, plant roots exert some binding effect on soil aggregates, as they produce polysaccharides and organic glues as plant residues decompose (Srinivasan *et al*., 2012). In addition, roots supply decomposable organic residues in the form of fine lateral roots, root hairs, sloughed-off cells from the root-cap, dead cells, mucilage, lysates and volatile and water-soluble materials to soil and support a large microbial population in the rhizosphere (Whites, 2006), as these roots enmesh fine particles of soil into stable macroaggregates, even when the roots are dead (Tisdall and Oades, 1982). Cover crops may also increase water-stable aggregation of soils indirectly by providing nutrition for soil animals, such as earthworms and mesofauna, enabling large populations to build up (Lawal, 2019). These earthworms stabilize soil aggregates and structure by ingesting soil and mixing it intimately with humified organic materials in their guts to form earthworm cast which generally contain more organic matter than the surrounding soil (Bossuyt *et al*., 2005; Weil and Brady, 2017). It is noteworthy that the protection offered by cover crop vegetation from the erosive forces of rain drops, mitigates soil erosion, and in so doing, strengthen soil aggregate stability.

Accumulation of organic residues is greatest at the soil surface because plant residues are left on the soil surface and not incorporated in the NT system, this enhances the integrity of water stable aggregates at the surface soil. However, organic residues left on the surface in no-till are actually more slowly decomposed than those incorporated by conventional tillage. No-till residues are in less intimate contact with the soil particles so their breakdown is delayed, increasing the length of time they remain as a protective surface barrier thus, higher soil aggregate stability in surface soil.

Conclusion

This study suggests that no-till, reduced till and cover cropping systems are effective management practices for the formation and stability of soil aggregates. Conservation till and the use of cover crops may be very important drivers of soil ecosystem functions. Since continuous growth of cover crops with minimal soil disturbance as in no-till and reduced till systems promoted development of higher water stable macroaggregate structure (especially at the surface soil) and higher aggregate stability that have greater capacity to execute vital soil ecosystem processes such as carbon turnover; as against the conventional tillage practice and the non-use of cover crop which disrupted soil macroaggregates and weakened aggregate stability. Any of the evaluated cover crops in this study, may be good choices to improve water stable aggregate in soils of the northern guinea savanna of Nigeria, better than the bare soil as no significant differences were observed among water stable aggregate of soils irrespective of the different cover crops evaluated.

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