

COLLOIDAL STABILITY AND POTENTIAL STRUCTURAL DEFORMATION INDEX OF FOUR NIGERIAN SOILS

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ABSTRACT

This study was undertaken to evaluate the effect of continuous cultivation on the colloidal stability and potential structural deformation index (PSDI) of four Nigerian soils. The four soils used for the study were; Entisol from Nsukka Hill, Ultisol from Nsukka poultry site, Inceptisol from Eha-Amufu and Inceptisol from Ikem, in Nsukka area of south eastern, Nigeria. The land use types considered were fallow and cultivated. The soils collected from 0-25cm depth were separated into five aggregate fractions, 5-2 mm, 2-1 mm, 1-0.5 mm, 0.5-0.25 mm and 0.25 mm, and changes in their colloidal stability and PSDI properties due to cultivation were determined for both dry and wet sieved fractions. The result of the study showed that the aggregates in the cultivated soils were less stable than those in the fallow soils. The colloidal stability result show less structural stability of the aggregates by the high DR values obtained. The correlation result between silt+clay and dispersion ratio (DR) for all the land use types showed that the contribution of silt+clay to the stability of these soils was low. No significant correlation was observed between Organic Carbon (OC) concentration and PSDI values and between silt + clay and total N, available P and OC in all the soils. The potential of the aggregates to disintegrate upon contact with water was more in Inceptisol at Eha-Amufu cultivated, IEh (C) 84.4% > Ultisol at Nsukka cultivated, UNsk (C) 74.4% > Ultisol at Nsukka fallow, UNsk (F) 72.0% > Inceptisol at Eha-Amufu fallow, IEh (F) 68.3% > Inceptisol at Ikem cultivated, Iik (C) 65.5% > Entisol at Nsukka fallow, ENsk (F) 65.2% > Inceptisol at Ikem fallow, Iik (F) 64.7% > Entisol at Nsukka cultivated ENsk (C) 61.8%. From the results of this study it is evident that the colloidal stability and PSDI of dry aggregates and wet-aggregates differ substantially even though their diameters are the same. Hence they will have differing impact on the soils.

Key word: Colloidal stability; PSDI; Silt; Clay, Fallow, Agriculture.

INTRODUCTION

Soil aggregation is a complex processes in soil ecosystem and a number of soil parameters and activities such as organic matter content, composition of soil minerals and soil organisms play an important role in soil aggregate formation. According to Degens, (1997) and Beare *et al.*, (1997), some of the most important processes in soil aggregation are flocculation of clay, cementation of dispersed clay or Fe and Al-oxy hydroxides, gluing effect of binding as polysaccharides' from plants, soil fauna and microbes, and cross-linking and enmeshment by fungal hyphae and plant roots. Hence soil particles aggregate as a result of gluing by bacterially produced polysaccharides' and physico-chemical interactions between silicate clay surfaces and functional groups of partially decomposed organic matter (Aspiras *et al.*, 1977, Aringhieri and Sequi 1978, Tisdall and Oades 1979, Sorensen, 1981). The labile fractions of soil such as carbohydrates was also reported by Tisdall and Oades (1982) to be involved in the aggregation of soil particles due to their binding and cementing actions. The physical enmeshing of soil particles and micro aggregates by mycorrhiza fungal hyphae, fine roots and root derived particulate organic carbon can as well stabilize soil aggregates (Tisdall and Oades 1982, Golchin and Dengiz 1997). Golchin and Dengiz (1997) emphasized that microbial decomposition of carbohydrates associated with aggregates and the resultant production of binding agents of mucilage and metabolites would promote the stability of soil aggregates.

The clay and silt fractions in the soil were found to be associated with organic matter concentrations in the different aggregate fractions (Christensen 1986) and there were significant correlations between aggregate stability and clay and silt contents. At the microscopic level, clay and organic matter act as bridges between the sand and silt particles, producing micro aggregates of soil (McLaren and Cameron 1996). Iron and aluminum oxide were found to be well correlated with aggregate stability (Panayiotopoulos and Kostopoulou 1989). Reid and Gross (1981) reported that roots and hyphae stabilize macro aggregates, defined as > 250mm diameter while the water-stability of micro-aggregates depend on the persistent organic binding agents which appear to be a characteristic of soil independent of management. This view was upheld by Mbagwu (1989a), when he argued that micro-aggregate < 0.20mm were held together by persistent binding agents like humus substances, and oxides of iron and aluminum. Macro aggregate however have their own life cycle repeating formation and break down depending on biological activity and fresh residue inputs (Denef *et al.*, 2001, Six *et al.*, 2000 and Bidisha 2010). Nevertheless, the effectiveness of various binding agents at different stages in the structural organization of aggregates forms the basis of a model which illustrates the architecture of an aggregate (Reid and Gross 1989). Tisdall and Oades (1982) classified organic binding agents into; transient, mainly polysaccharides, temporary, roots and fungal hyphae and persistent, resistant aromatic components associated with polyvalent metal cations and strong polymers.

The growth of soil fungi can produce sufficient mycelia to aggregate soil particles (Swaby 1949, Bond and Harris 1964), but this mechanical binding effect may be transient because the hyphae themselves are susceptible to microbial decomposition. More so, many soil microbes produce polysaccharides (Hepper 1975) and it is generally agreed that such compounds are important in binding soil particles into larger units (Harris *et al.*, 1966, Martin 1971). This might be the reason why Skinner (1979) stressed that vigorous root and microbial activity in pasture soil may well explain the large proportion of highly stable aggregates usually found under grass. Earlier in their studies, Harris *et al.*, (1966), maintained that the formation of soil aggregates that are stable to the action of water or mechanical forces depend on many factors, some of which are microbiological. Furthermore, the introduction of grasses in structural improvement and the increase is believed to be a result of physical enmeshment by roots and hyphae (Tisdall and Oades 1979), and cementing action of periodate-tetraborate and pyrophosphate sensitive materials (Reid and Gross 1981, Angers and Mehuys 1989).

Studies done by various workers have also helped to x-ray and reassess the effect of organic matter and microbial processes in binding, cementing and aggregating of soil particles. For instance, it was discovered that organic materials act as transient, temporary or permanently binding agents at different levels of aggregation (Hadas 1987, Dexter 1988, Perfect and Kay 1991, Tisdall and Waters 1991, Piccolo 1996). The location of the organic matter within the aggregates influenced their accessibility for microbial decomposition (Elliot 1986), the distribution of the microbial biomass within the aggregates varied with the intensity of land use (Gupta and Germida 1988, Kandeler and Murer 1993). Miller and Jastrow (1990), and Monrozier *et al.*, (1991) reported that the stability of the aggregates is influenced by the contents of the microbial biomass and root and fungi hyphae within the aggregates. Piccolo and Mbagwu (1990) found organic matter very effective in stabilizing silt and clay particles within dry micro aggregates with organic waste amended Italian soils. Though the stability of the silt-plus-clay particles correlated significantly with the humic acid content, there was no significant correlation with the total organic matter (Mbagwu and Piccolo 1998).

Laboratory studies using synthetic oxide precipitates have shown that Al and Fe-oxy hydroxides promote aggregation (EL-Swaify and Emerson 1975, Oades 1984), though the effect of oxides on soil properties are variable with respect to the nature and amount of oxides and the environment of their pedogenic formation (Schnert-Mann and Taylor 1989). Fe-oxy-hydroxide was found to be less effective compared to Al (OH), polymers in maintaining the stability of soil aggregates (EL-Swaify and Emerson 1975, Hsu 1989), probably due to the fact that the Fe-oxy hydroxides make stronger tendency than Al (OH)₃ to crystallize, thus having lesser cementing effect except in soils frequently alternating between oxidized and reduced states (Frankel and Sheinberg 1980). Poor aggregates, according to Hsu (1989), do not necessarily indicate that they do not affect aggregation. Angers and Mehuys (1989) stressed that water extractable and acid-extractable carbohydrate carbons are more strongly correlated with the stability of macro-aggregates than total organic carbon or total extractable carbohydrate.

Nonetheless, the stability of soil aggregates can decline or decrease with the reduction in carbohydrate levels following microbial decomposition and the production of mucilage and metabolite glues will equally reduce (Golchin *et al.*, 1997). Soil structural stability and soil organic carbon content usually decrease and changes the distribution of soil aggregates with cultivation (Six *et al.*, 2000, Eynard *et al.*, 2004). While Young and Young (2001) reported that soil structural stability will decrease under most forms of cultivation. Soil aggregate formation can as well be inhibited by tillage, traffic with agricultural machines and rainfall that accelerate aggregate breakdown (Bronick and Lal 2005) they also reported that temporal and spatial heterogeneity and complexity in soil continuum makes it difficult to directly measure the aggregation and carbon storage in soil. Most of the works cited above on the stability of soil aggregates on different soil types and management were mainly in the temperate region where the soils are very different from those in the tropics. Therefore the research was undertaken to study the colloidal stability and potential structural deformation index of four Nigerian soils.

Materials and Methods

Study Area and Sampling

Soil samples from the 0-25cm depth were collected from cultivated and adjacent fallow lands in four different locations in Nsukka area of south eastern Nigeria. Care was taken to minimize disturbance during sampling and transportation. The area has a rainforest savannah type of vegetation with a mean annual temperature of 24°C. The area lies within latitude 06° 61'N and longitude 07° 25'E of Nigeria. The soils

sampled for the study are classified according to soil taxonomy as an Ultisol, belonging to the sub-group, Typic Kandistult (Nkpologu series), Entisol belonging to Lithic Ustorthent (Uvuru series), while the other two soils belong to Vertic Inceptisol (SSS, 1992). These soils have been under cultivation for over 8-years while fallow soils were 3 - 4years old. The cultural practices adopted in these soils were slashing and burning and only Hoe is used for tillage. Fertilizer application is basal and it is mainly Nitrogen phosphorous potassium fertilizer (NPK). The Figure below is map of Nigeria showing the sampling area and where the research was conducted.



FIG 1.

Table 1 Location, Classification and Land use type

Location		Classification	Treatment symbol	Land use type
Nsukka Hill	Site	Lithic Ustorthent	ENsk (F)	Fallow
		(Uvuru series)	ENsk (C)	Cultivated
Nsukka	Poultry Site	Typic Kandistult	UNsk (F)	Fallow
		(Nkpologu series)	UNsk (C)	Cultivated
Eha-Amufu	Site	Inceptisol	IEh (F)	Fallow
		(With vertic properties)	IEh (C)	Cultivated
Ikem site		Inceptisol	Iik (F)	Fallow
		(With vertic properties)	Iik (C)	Cultivated

Sample Preparation

The soil samples were air-dried at room temperature and then sieved through a 5.00mm sieve. Two hundred and fifty grams (250g) of the sieved sample were transferred to the upper most of a nest sieve of sizes 2, 1, 0.5 and 0.25mm. They were shaken mechanically for 10 minutes. Further sieving by hand was done where

necessary. The procedure described by Kemper and Chepil (1965) was used in the separation of the following aggregate fractions 5-2, 2-1, 1-0.5, 0.5-0.25 and < 0.25mm. The separation continued until enough quantity of each fraction was collected for further analysis.

Laboratory method

The mean weight diameters of dry aggregates (MWDD) was determined by the method of Kemper and Chepil (1965), while the method of Kemper (1965), was used to determine the mean-weight diameter of wet aggregates (MWDW). To assess the relative susceptibility of the soils to disintegrate upon wet-sieving the potential structural deformation index, PSDI (Mbagwu and Bazzoffi, 1989) was computed thus:

$$\text{PSDI} = \left\{ 1 - \frac{\sum_{i=1}^n \varepsilon (\theta_i w_i)}{\sum_{i=1}^n \varepsilon (\theta_i d_i)} \right\} \times 100$$

Where:

θ_i = Mean diameter of the i th size Fraction (mm).

w_i = Proportion of the total mass retained in the i th size fraction (from wet-sieving) gg^{-1} .

d_i = Proportion of the total mass retained in the i th size fraction (from dry sieving) gg^{-1} .

n = Number of sieve (size) fraction used.

The PSDI was used to normalize the changes in distribution of dry and wet aggregates to enable a realistic comparison of the relative effects of land use across the different soils to be made.

Colloidal stability

The procedure of Middleton (1930) was used. The procedure involved determining the percent silt + clay in water-dispersed samples (A) and that in sodium resin-dispersed samples (B). The index $(A/B \times 100)$ known as the dispersion ratio DR, is a measure of the potential of the individual aggregates to resist break down upon contact with water molecules. In this study, 20g sample from each aggregate fraction was soaked in either distilled water or sodium hexametaphosphate solution for 24 hours, followed by end-over-end shaking on a mechanical shaker for 30 minutes at 10 revolutions per minute. The dispersed silt + clay were determined by the hydrometer method.

Organic Carbon

Walkley and Black method (1934) as modified by Allison (1965) was used to determine OC. The procedure involved the oxidation of the soil OM with potassium dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$) using concentrated sulphuric acid (H_2SO_4) and the percentage OC found by titrating with IN ferrous ammonium sulphate solution.

Available Phosphorous

This was determined by Bray and Kurtz (1934), Bray 11 method (0.03N ammonium Fluoride 0.1N HCL). The available phosphorous was read off from standard curve after obtaining the optical density from a photo-electric colorimeter.

Total Nitrogen

The Kjeldahl method of Bremner (1965) using $\text{CuSO}_4\text{-Na}_2\text{SO}_4$ catalyst mixture was used to determine total nitrogen. The ammonia (NH_3) from the digestion was distilled with 45% NaOH into 2.5% Boric acid and determined by titrating with 0.05N HCL.

Data Analysis

Little and Hills (1972) simple linear regression and correlation analysis was used to analyze the data obtained from this work in order to identify which intrinsic and dynamic properties influenced the stability of the aggregates most. While least significant difference (LSD) at 5% was used to compare the treatment means obtained in PSDI and DR. The cumulative aggregate distribution from dry and wet sieving procedures of each aggregate size was later drawn with Corel draw software to show a vivid picture of PSDI distribution of each soil type.

Result and Discussion

Colloidal Stability

The values of dispersion ratio (DR) given in Table 2, show significant ($p=0.05$) differences among the soil types and land use systems. Higher dispersion ratio was observed in lik (F), while the least among the soil types and land use system was obtained from UNsk (F). The DR result also show lower values in cultivated soils compared to the fallow soils with the exception of UNsk where the cultivated value was higher than that of the fallow soil. The value obtained from IEh however, indicated that cultivation had no effect on the dispersion ratio. The nature of the result so obtained from these soil types and land use systems probably suggests that there was no decrease in the aggregate stability of these soils due to cultivation. The higher DR values show less structural stability of the aggregates.

Table 2: Aggregate stability of the fallow and cultivated soils as evaluated by two different indices

SOILS	PSDI	DR
ENsk (F)	65.16	72.73
ENsk (C)	61.84	66.80
UNsk (F)	71.98	55.55
UNsk (C)	74.41	62.50
IEh (F)	68.33	76.47
IEh (C)	84.41	76.47
lik (F)	64.68	87.50
lik (C)	65.51	73.33
Mean	69.54	71.40

LSD (0.05)

3.64

4.57

PSDI = Potential structure deformation index, DR= Dispersion ratio, LSD = Least significant difference, F = Fallow, C = Cultivated, ENSK = Entisol at Nsukka, UNSK = Ultisol at Nsukka, IEh = Inceptisol at Eha-Amufu, Iik = Inceptisol at Ikem.

The non-significant correlation between silt + clay and DR for all the land use types (Table 3) showed that the contribution of silt + clay to the stability of these soils was low. Allison, (1973) observed that clay stabilizes soil aggregates. Thus the quantity of clay present may be an important factor in stabilizing soil aggregates. Also Heinonen (1955) suggested that a positive and significant correlation between aggregate stability and clay content should be expected in soils containing more than 30% (W/W) clay. The result could also be attributed to the nature of microbes, organic matter, or clay, Fe and Al oxide contents of these soils. Hepper (1975) observed that many soil microbes produce polysaccharides and it is generally agreed that such compounds are important in binding soil particles into larger units (Martin, 1971). Miquel and Norton (1994) reported that aggregate stability is largely dependent upon OM, clay, Fe and Al oxide contents. Also Panayiotopoulos and Kostopoulou (1989) found Fe and Al oxide to be well correlated with aggregate stability.

Table 3 Correlation of silt + clay (%) and OC % with other Soil Properties (N=8)

Independent Variable	Dependent Variable	Correlation Coefficient (r)
Silt + clay %	DR %	- 0.824 ^{ns}
	Total N %	- 0.146 ^{ns}
	Avail. P (Mgkg ⁻¹)	- 0.644 ^{ns}
	OC %	- 0.213 ^{ns}
OC %	PSDI %	- 0.364 ^{ns}
	DR %	- 0.438 ^{ns}
	Total N %	- 0.949 *
	Avail. P (Mgkg ⁻¹)	- 0.364 ^{ns}

* Significant at P = 0.05 ns = not significant.

Potential structure deformation index:

The PSDI values result given in Table 2 show higher values among the soil types and land use system, highest PSDI value among the soils was obtained from IEh (C) and this was significantly (p=0.05) different among the soil types and land use systems. The potential structural deformation index (PSDI) is used to normalize aggregate distribution between the dry and wet sieving procedures, as to obtain valid comparisons between land use types. The lower the percentage, the more resistant is the soil to disruptive forces. The cumulative aggregate distributions from dry-and wet sieving procedures for the ENSk are given in Fig 2, UNSk in Fig 3, and IEh in Fig 4 and Iik in Fig 5. (See Table 1 for the explanation of the symbols and Figure 1 for sampled areas).

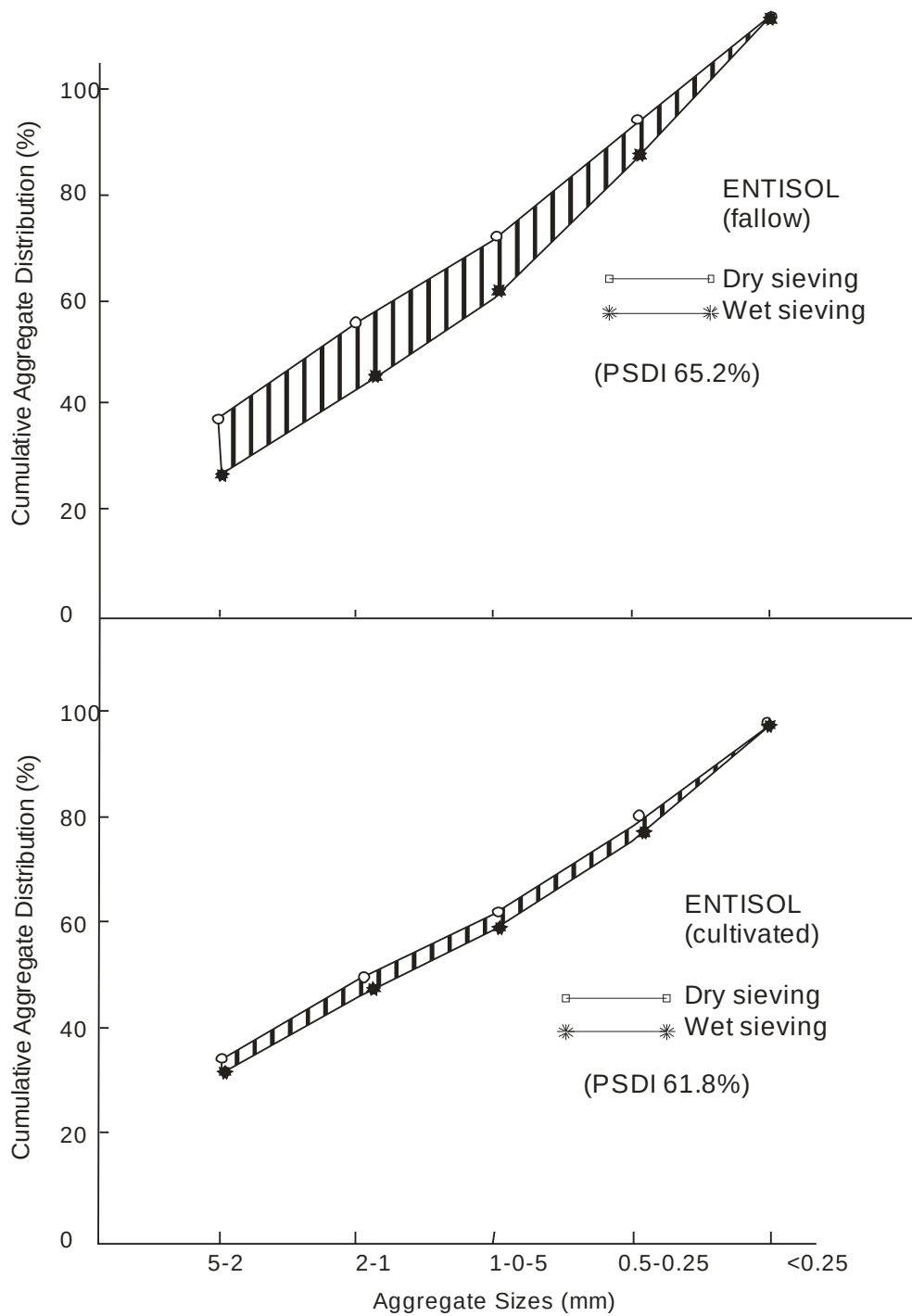


FIG 2: Distribution of aggregate obtained from dry and wet sieving procedures in an Entisol (Nsukka Hill Site) under different land uses. (PSDI = Potential structure deformation index)

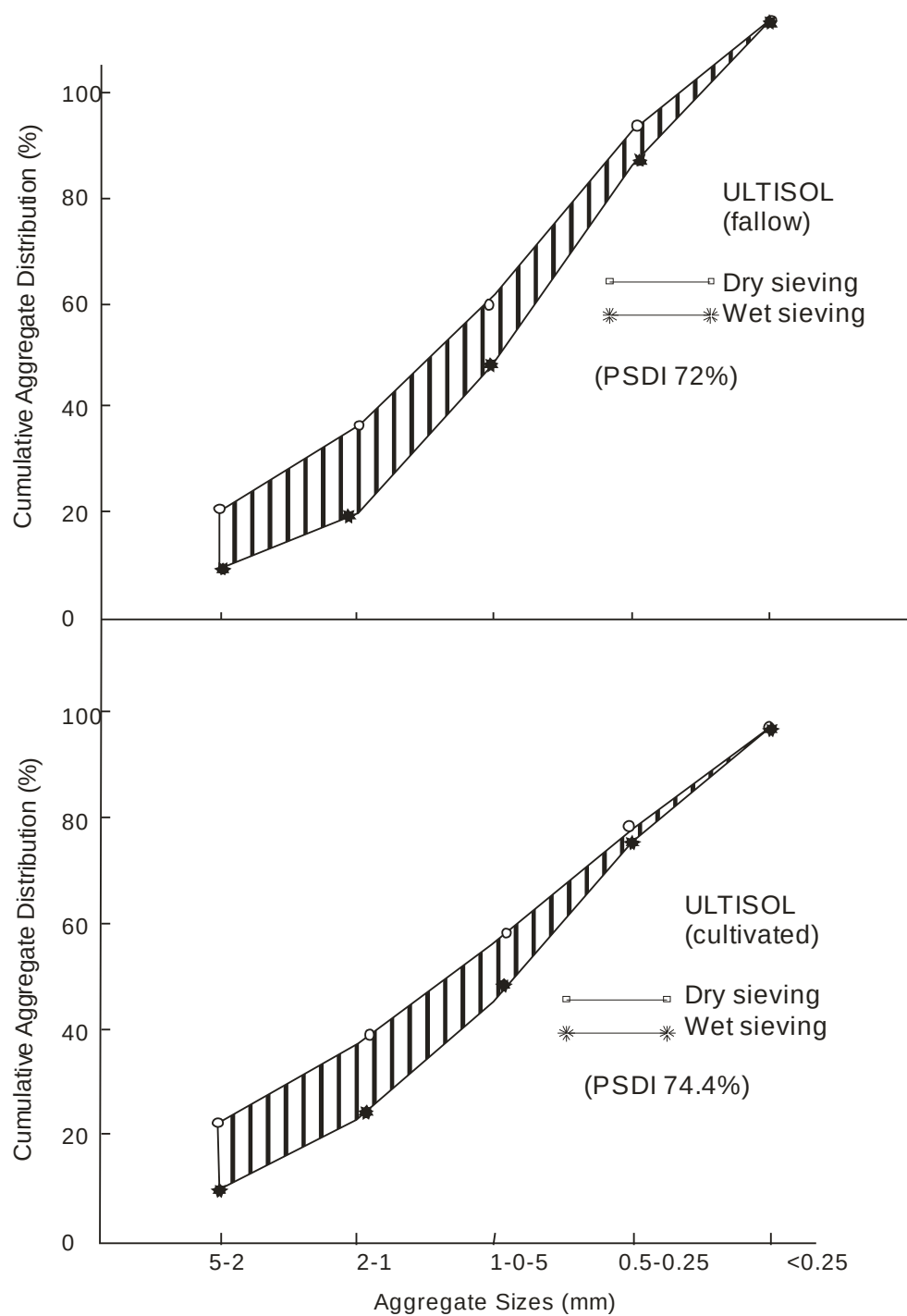


FIG 3: Distribution of aggregate obtained from dry and wet sieving procedures in an Ultisol (Nsukka Poultry Site) under different land use (PSDI = Potential structure deformation index)

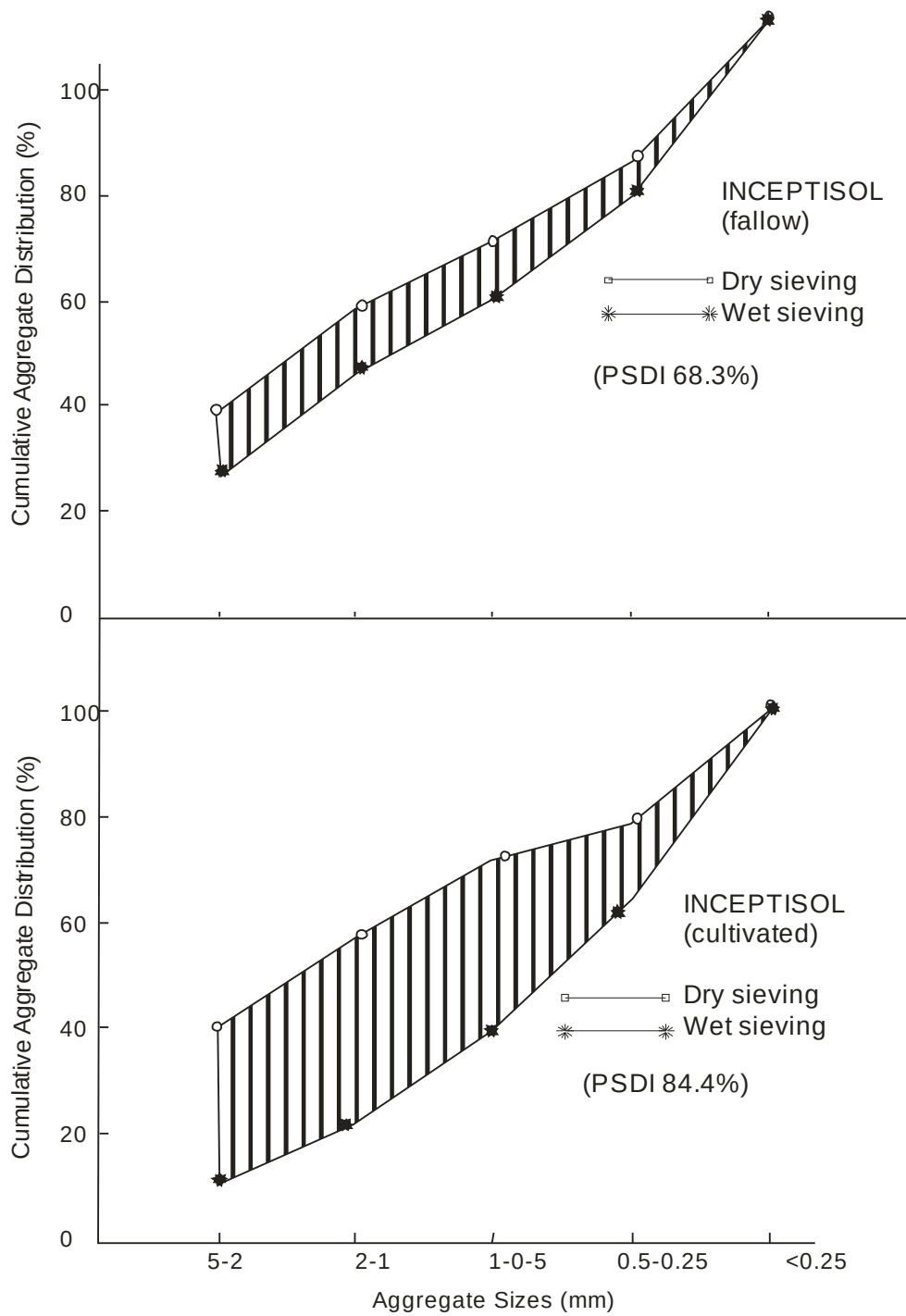


FIG 4: Distribution of aggregate obtained from dry and wet sieving procedures in an Inceptisol (Eha-Amufu Site) under different land use (PSDI = Potential structure deformation index)

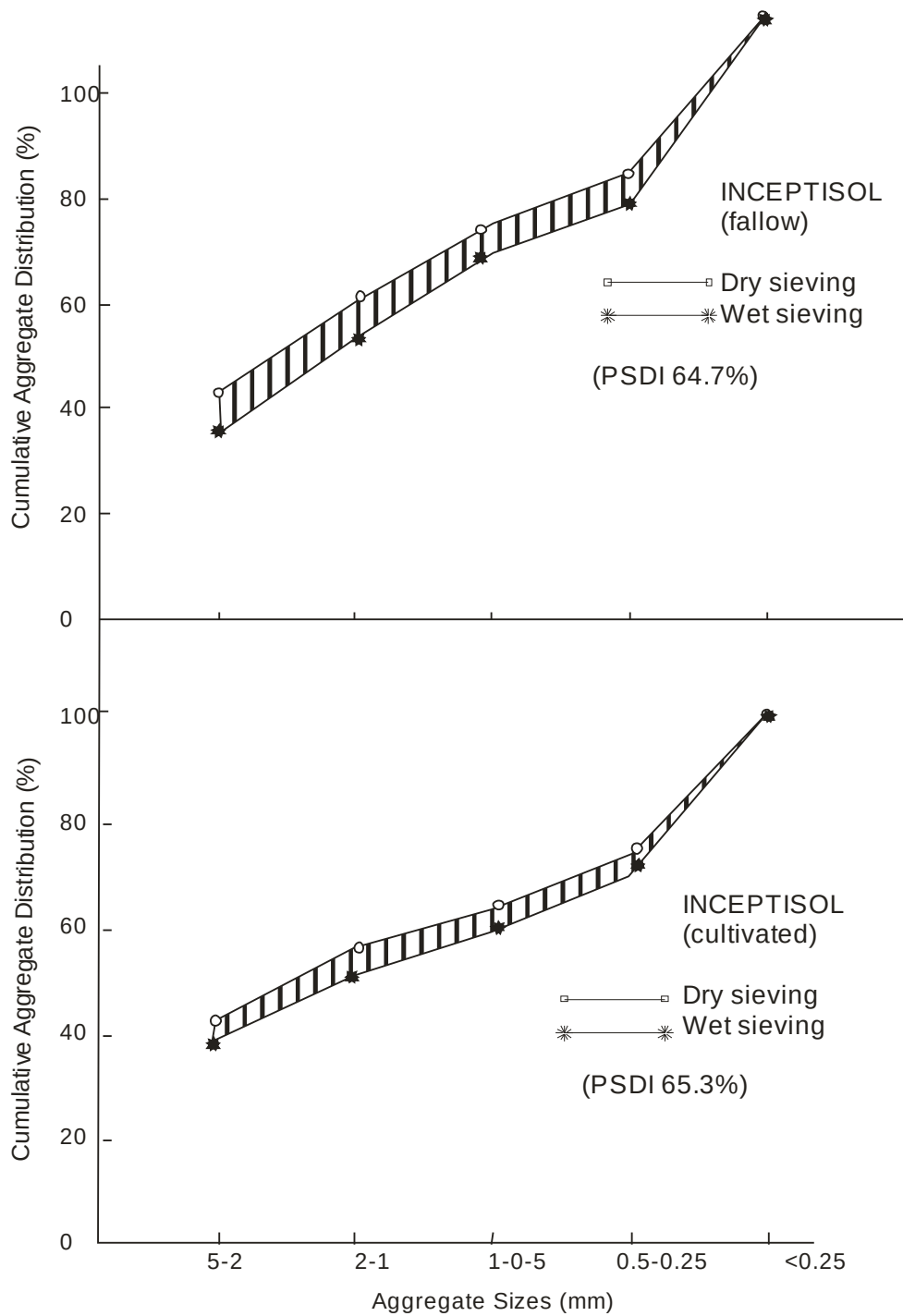


FIG 5: Distribution of aggregate obtained from dry and wet sieving procedures in an Inceptisol (Ikem Site) under different land uses. (PSDI = Potential structure deformation index)

The area under the two curves indicates the relative resistance of the dry aggregates to disruption by water. The smaller the area the more resistant is the soil to the disruptive forces. This showed that the aggregates of the fallow soils were more resistant to disruptive forces compared to those of the cultivated soils. This statement is only true for the PSDI of IEh given in Fig 4.

The correlation coefficient between OC concentration and PSDI values of these soils were small and non-significant (Table 3). This indicates that the contributions of organic matter to the stability of the aggregates of these soils were small. Mbagwu and Bazzoffi (1989) made similar observation on Italian soils. Generally, the soils are not resistant to deformation because the PSDI values are large.

Nonetheless, the PSDI showed an order of vulnerability to disintegration upon contact with water molecules of IEh (C) 84.4% > UNsk (C) 74.4% > UNsk (F) 72.0% > IEh (F) 68.3% > Iik (C) 65.5% > ENsk (F) 65.2% > Iik (F) 64.7% > ENsk (C) 61.8%. In all the soils a significant correlation between OC and total N was established (Table 3). This indicates that the source of total N in the soils is from OM. The non-significant correlation between silt + clay and total N, available P and OC (Table 3) in all the soils signifies that the sources of these nutrients are not from silt + clay contents in the soils.

Conclusion

From the study, it was found out that cultivated soils in some of the soils studied did not have less stable aggregates nor disintegrated faster than those of the fallow soils when they came in contact with water. The PSDI values were found to be large, indicating that the soils are not resistant to deformation. There has to be a land use strategy to maintain stable aggregation but at the same time allow an ordered agricultural production of crops.

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