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RECIPROCAL RELATIONSHIPS BETWEEN AGGREGATE STABILITY AND ORGANIC CARBON CHARACTERISTICS IN A FORESTED ECOSYSTEM OF NORTHERN NIGERIA

[RELACIONES RECIPROCAS ENTRE LA ESTABILIDAD DE AGREGADOS Y CARACTERISTICAS DEL CARBONO ORGANICO DEL SUELO EN UN ECOSISTEMA FORESTAL DEL NORTE DE NIGERIA]

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SUMMARY

Soil organic matter associated with different size aggregates differ in structure and function; therefore, play different roles in soil organic carbon (SOC) turnover. This study assessed the relationship between aggregate stability and soil organic carbon fractions in a forested soil. Aggregate stability characterized by mean weight diameter (MWD) was correlated with the various pools of SOC in a regression model. Mean weight diameter presented a 46% influence on total organic carbon (TOC) while, TOC accounts for 21.8% of aggregate stability. The unprotected and physically protected soil organic carbon did not significantly dictate stability of these soils. However, chemically protected and biochemically protected SOC influenced significantly aggregate stability of these forested soils.

Keywords: soil organic matter; mean weight diameter; aggregate stability; soil quality; savanna.

RESUMEN

La materia orgánica del suelo asociada con diferentes tamaños de agregados, difiere en estructura y función; así mismo, juega diferentes roles en la rotación de carbono en el suelo (SOC). Este estudio evaluó la relación entre la estabilidad de los agregados y las fracciones de carbono orgánico en suelos boscosos. Se correlacionó la estabilidad de los agregados a través del diámetro de peso medio (MWD) y un grupo de SOC en un modelo de regresión. El diámetro de peso medio presentó un 46% de influencia sobre el total del carbono orgánico (TOC) así mismo, TOC describió un 21.8% de la estabilidad de los agregados. La protección y no protección del carbono orgánico del suelo no dictaminó significativamente la estabilidad de esos suelos. Sin embargo, el SOC químicamente y bioquímicamente protegido influenció significativamente la estabilidad de los agregados de esos suelos boscosos.

Palabras clave: Materia orgánica del suelo; diámetro de peso medio; estabilidad de agregado; calidad del suelo; sabana.

INTRODUCTION

The total organic matter in soil encompasses the various pool of soil organic matter (SOM) namely; active, slow and passive pools. Therefore, recognizing the susceptibility of the different pools of SOM to microbial degradation is a most useful approach to define SOM quality (Brady and Weil, 1999). The turnover time and carbon storage potential of these various pools affect the formation and stability of soil aggregates.

Soil organic matter associated with different soil size aggregates differ in structure and function (Christensen, 1992), and therefore, play different roles in soil organic carbon (SOC) turnover. This relationship is crucial to understand SOC dynamics, because SOM influences soil physical and chemical properties which are paramount to nutrient cycling and will consequently have effect on forest productivity. Forest vegetation plays a key role in atmospheric carbon sequestration, thereby mitigating greenhouse effect.

The formation distribution and turnover of SOM are largely affected and controlled by climate (chiefly, temperature and moisture) and modified by vegetation, parent materials and human activities. Overtime, SOC is allocated into various pools as a result of root growth, litter fall and subsequent microbial decomposition; these pools are defined on the basis of relative recalcitrance which governs their residence and turnover times. This study aimed to assess the relationship between aggregate stability and SOC fractions in a forested soil.

MATERIALS AND METHODS

Location and Soil sampling

Soil samples were collected from the Afaka Forest Reserve, Kaduna, Northern Guinea savanna ecological zone (Keay, 1959) of Nigeria, coordinates 10° 33’ and 10° 40’ north and 07° 15’ East, annual rainfall of 1270 mm and 593 m altitude. Sampling was done in April, 2006 from seven (7) selected treatment plots planted to: *Acacia senegal, Azadirachta indica, Eucalyptus camadulensis, Khaya senegalensis, Prosopis africana, Tamarindus indica* and *Tectona grandis.* A stratified random sampling method was adopted to collect soil samples by hypothetically dividing each plot into three (3) subdivisions, representing three replications, since plots were not replicated and plot sizes were very large. In each replication, composite soil samples at four (4) different points were taken and then bulked. Soil samples from each location were taken from 0-25 cm depth and labeled for ease of identification.

Laboratory Analyses

Aggregate fractionation

A 200 g of air dried bulk soil (passed through a 5 mm sieve) was wetted by rapid immersion (slaked), then sieved in water for one minute using sieve sizes of 2 mm, 0.25 mm and 0.053 mm, with an average stroke per minute of 36, 14 and 3 for each of the sieve sizes respectively.

The sieving was carried out in the order of decreasing mesh size. After sieving with the initial sieve size (2 mm) the filtrate was transferred onto the proceeding sieve (0.25 mm), and then 0.053 mm sieve. The <0.053mm aggregate fraction was allowed to settle down and the water was decanted gently. The fractionated aggregates were oven dried at 60°C for 48 h and weighed.

The proportion of each aggregate fraction was corrected for sand and mean weight diameter determined. However large macroaggregate >2mm were not used in computing or calculating MWD, because the proportion of aggregates >2mm recovered after the wet sieving were too small in weight to be corrected for sand (sand free fraction).

The proportional weight of sand free aggregates is given as

$$\frac{\text{Weight of aggregate fraction - \% sand content}}{\text{Weight of bulk soil - \% sand content}}$$

(Masri and Ryan, 2006)

Mean weight diameter (MWD) was determined thus:

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

Where xi = mean diameter of sieve proceeding and preceeding

Wi = proportional weight of sand free aggregates

Soil organic matter fractionation

Soil organic carbon content was determined in each of the aggregate fractions (2-0.25, 0.25-0.053 and <0.053mm) by the dichromate oxidation method (Nelson and Sommers, 1982).

The following fractions were identified.

Sieve size	Measure organic matter	Conceptual soil organic matter
2-0.25 mm	Fine particulate organic matter	Unprotected
0.25-0.053 mm	Intra aggregate particulate organic matter	Physically protected
<0.053 mm	Silt and clay associated organic matter	Chemically protected

Sand free carbon concentration was calculated in aggregate fractions greater than 0.053mm as:

$$\text{Sand free C fraction} = \frac{\text{..Cfraction……………………}}{\text{1-[sand proportion] fraction}}$$

(Denef *et al*., 2001)

Biochemically protected soil organic matter (SOM)

The biochemically protected SOM was determined by acid hydrolysis (Tan *et al*., 2004). Non hydrolysable carbon was determined in the acid hydrolyzed samples by dichromate oxidation method as described by Nelson and Sommers (1982). The quantity of the non hydrolysable SOM was referred to as the biochemically protected SOM.

Data analysis

Soil aggregate stability characterized by mean weight diameter (MWD) was correlated with the various pools of SOC and macroaggregates in a regression model in accordance with the procedures of Steel and Torrie (1984).

RESULT AND DISCUSSION

Relationship between Soil Macroaggregates And Mean Weight Diameter

When the regression graph of large macroaggregate (>2mm)was plotted against mean weight diameter (Figure 1a) and vice versa (Figure1b), a quadratic equation gave the best fit with r^2 values of 0.5364 and 0.5408 respectively, implying that the proportion of large macroaggregate fraction in any soil dictates more than 50% of the MWD value.

Furthermore, both mean weight diameter and large macroaggregate fraction could be dependent on one another establishing a significant relationship ($P>0.05$) and indicating that MWD was directly proportional to large macroaggregate. Thus in a well aggregated soil (with high value of MWD), a large proportion of macroaggregate fraction is expected. The non-use of large macroaggregate in computing MWD in this study could be responsible for its low r^2 value ($P\geq0.05$) in the regression graph (Figure 1a and b), compared to the r^2 values of the regression graph of small macroaggregate (2-0.25mm) versus MWD (Figure 1c and d).

The graph of small macroaggregate against mean weight diameter and vice versa revealed that the best fit equation was quadratic as indicated by r^2 values of 0.9936 and 0.972 (Figures. 1 c and d respectively), indicating that the MWD is dependent upon small macroaggregates and showing strong dependence of both variables (small macroaggregate and MWD) on each other($P\geq0.01$).

Relationship between Soil Organic Carbon Pools and Aggregation

The relationship between total organic carbon (TOC) and MWD was best presented with a cubic regression model. TOC vs MWD and MWD vs TOC had r^2 values of 0.464 and 0.218 (Figs. 2a and b respectively). In either case, the relationship was not significant ($P\geq0.05$), indicating the independence of these factors.

Regression graph (Figure 2c and d) showed that there is a weak relationship between unprotected organic carbon (UPOC) and MWD. It was best presented by a cubic equation and showed r^2 value of 0.1885 when UPOC was plotted against MWD, and a r^2 value of 0.0306 when MWD was plotted against UPOC (Figure 2c and d respectively). The non significance of this regression further confirms that UPOC have little influence on soil aggregate stability, since UPOC provides readily accessible nutrition/nourishment for soil microbes (Six *et al.*, 2000). Furthermore at the time of soil sampling in this study, (The month of April which marks end of dry season, shortly before the onset of the rainy seasons), the rate of litter decomposition may exceed litter input in the forest ecosystem, thus little of the UPOC will be available, therefore minimal contribution of this carbon pool to soil aggregate stability is expected at this time.

The relationship between MWD and physically protected organic carbon (PPOC) was also best shown by a cubic regression model, though the relationship was not significant. An r^2 value of 0.3172 was obtained when PPOC was plotted against MWD (Figure 2e) and an r^2 value of 0.2081 was presented by graph of MWD against PPOC (Figure 2f). The relationship between PPOC and MWD (Figure 2e and f) indicated a better influence of soil aggregation than that of the UPOC and MWD (Figure 2 c and d) hence explaining the longer turnover time of PPOC in soil (Brady and Weil, 1999) than the UPOC. The influence of PPOC on MWD and vice versa showed that these parameters explain between 21 and 32%. A high value MWD may suggest that there is a reasonable amount of PPOC in that soil.

The relationship between soil aggregate stability as characterized by MWD and chemically protected organic carbon (CPOC) was also best represented by a cubic equation regression model. An r^2 value of 0.3899 was obtained when CPOC was a dependent variable (Figure 2g) while an r^2 value of 0.8454 was obtained when CPOC was an independent variable (Figure 2h). The extent of soil aggregate stability is a function of its CPOC. Furthermore it could be deduced from the regression graphs that CPOC influences soil aggregate stability (Figure 2h) more than other aggregate associated carbon evaluated in this study. The value of MWD could explain less than 40% of CPOC however, CPOC explains over 80% of the MWD value. The formation of stable organomineral complexes is an important mechanism of soil carbon sequestration (Lal *et al.*, 2003) and its stabilization effect is principally observed at microaggregation level. However, it can also indirectly increase macroaggregation through a stimulation of microbial activity particularly, when Ca is present (Six *et al.*, 2004).

The reciprocal relationship between aggregate stability and CPOC is not well pronounced as the amount of CPOC present in soil is not a function of the soil aggregate stability rather; CPOC dictates the level of stability of soil aggregates (Figure 2g and h). These aggregates indicate that CPOC increases the stability of soil aggregates which in this case was represented by MWD.

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Regression graph showed that a cubic equation gave the best fit, when Biochemically protected organic carbon (BPOC) was plotted against soil aggregate stability (Figure 2i), this was characterized by mean weight diameter (MWD), with an r^2 value of 0.5241. However, when MWD was plotted against BPOC an r^2 value of 0.744 was obtained (Figure 2j). The significance of this relationship is an indication that both BPOC and MWD are interdependent

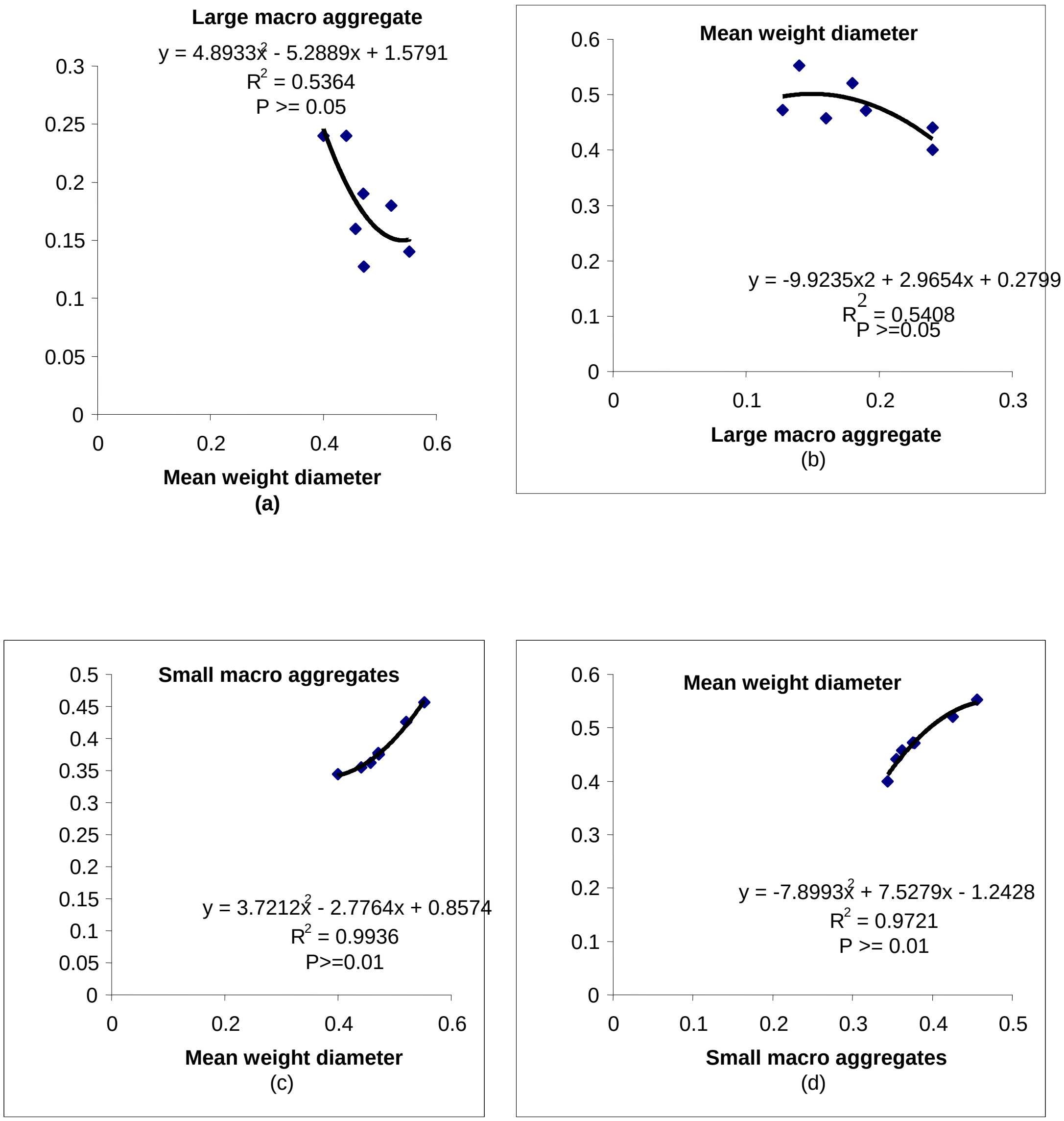

Figure 1: Relationship between Macro aggregate and Mean weight diameter

However, the extent of aggregate stability in a soil may be more dependent on BPOC content which is at a higher significant (P≥ 0.01) level (Figure 2j). Hence explaining that a higher BPOC content in soil would induce a stronger soil aggregate stability than a high MWD would induce increase in BPOC content in soil. The BPOC involves biomasses that have been converted into humic substances which are relatively resistant to microbial decomposition and have a long turnover time. Carbon pools are recalcitrant pools and therefore, vital in soil aggregation

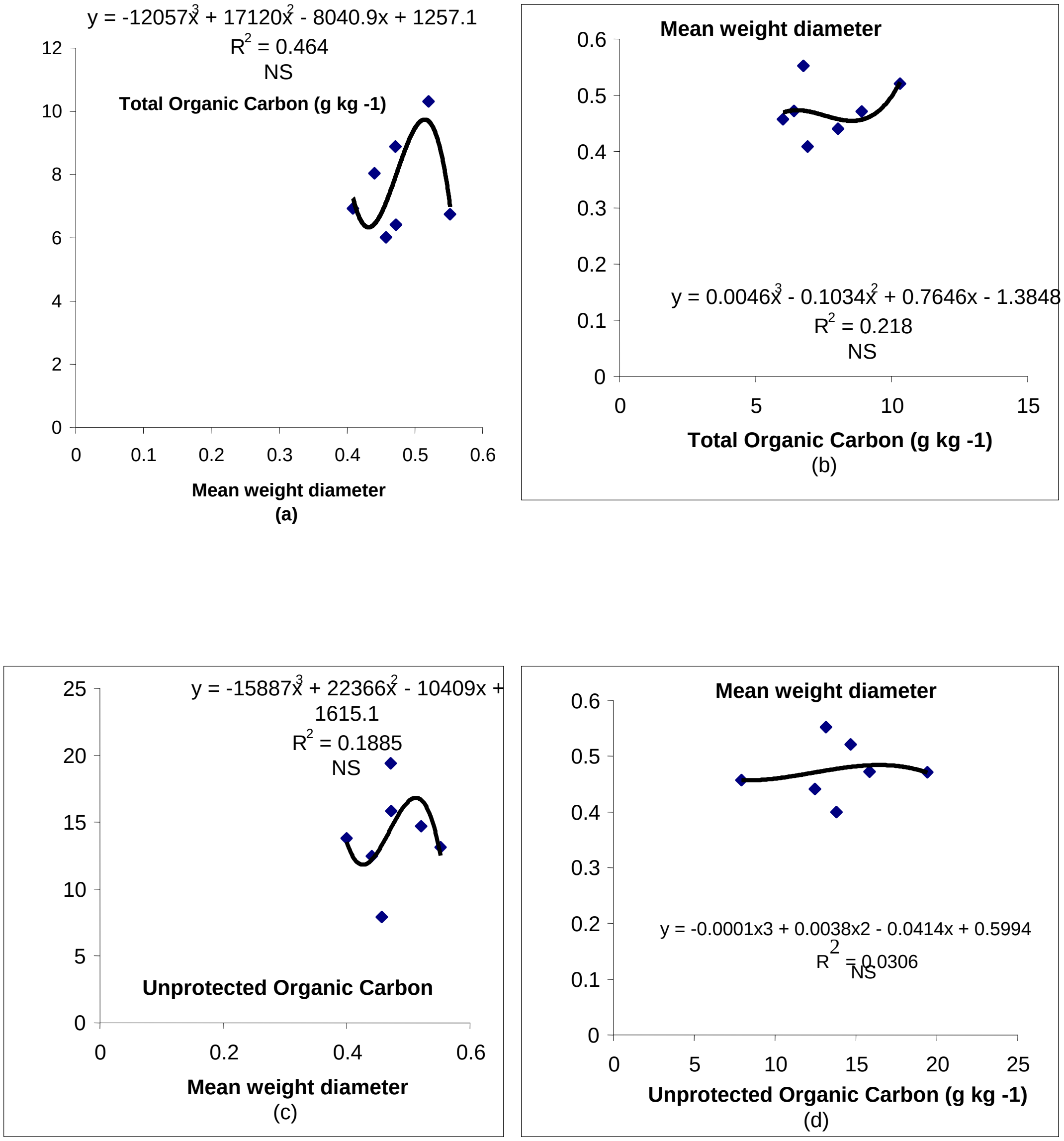

Figure 2: Relationship between Soil Organic Carbon and aggregation

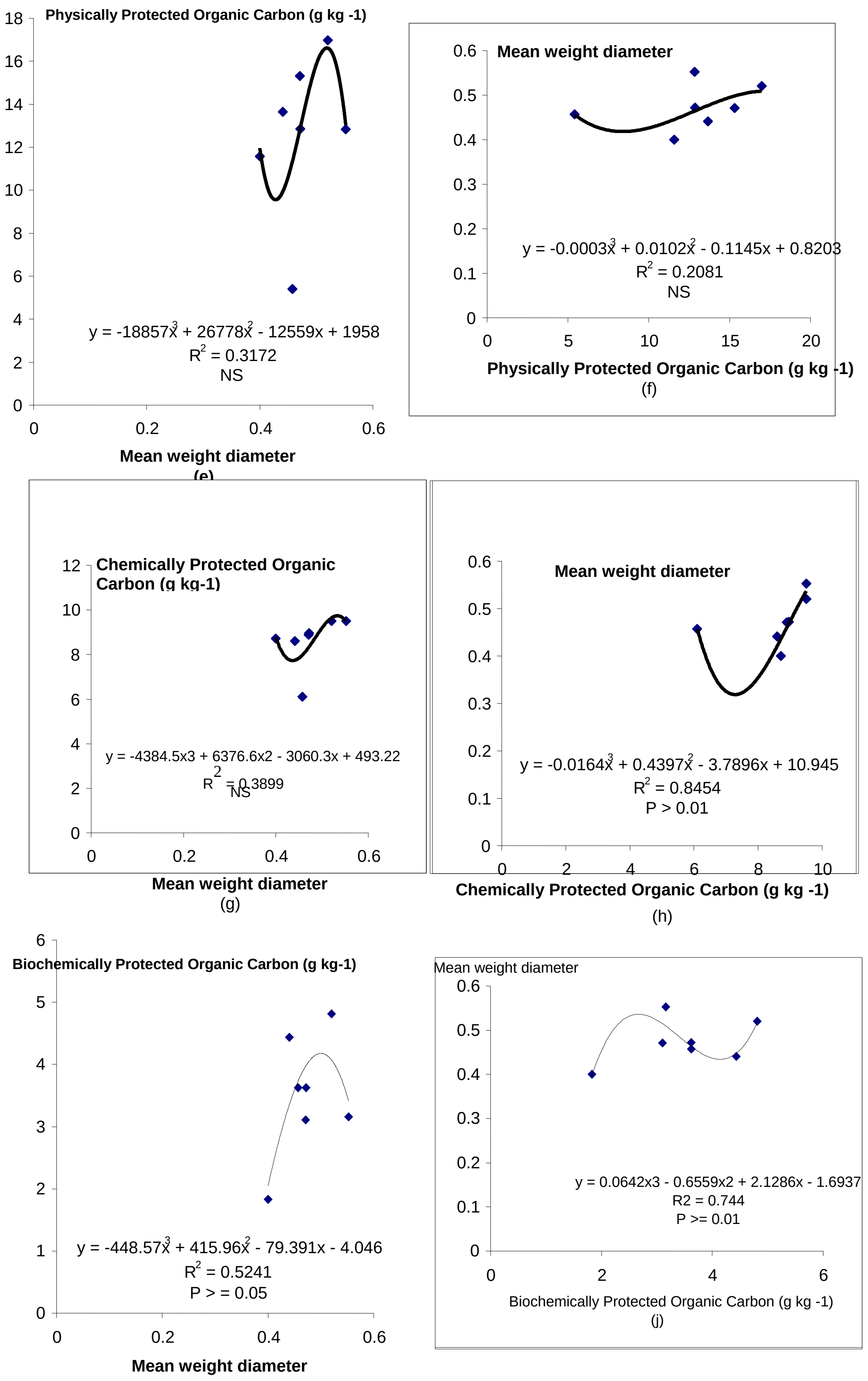

Figure 2: Relationship between Soil Organic Carbon and aggregation. (continues from previous page)

CONCLUSION

A strong relationship was observed between SOC pool and aggregation especially with BPOC. In a structurally stable soil, with high proportion of macroaggregate, Reciprocal relationship may not exist between TOC content and soil aggregate stability. However, whenever there is a significant relationship between soil aggregate stability and any of the SOC pools, specifically the BPOC (recalcitrant) and CPOC, then a good soil aggregate stability may be expected concluding that, in certain instances, TOC may not give precise prediction of the degree of aggregate stability in soil.

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