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EFFECT OF LOW AND HIGH- KINETIC ENERGY WETTING ON QUALITY OF SEDIMENT PRODUCED BY INTERRILL EROSION

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ABSTRACT OF DISSERTATION

Eduardo A. Rienzi

The Graduate School

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2010

EFFECT OF LOW AND HIGH- KINETIC ENERGY WETTING ON QUALITY OF SEDIMENT PRODUCED BY INTERRILL EROSION

ABSTRACT OF DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Agriculture at the University of Kentucky

By
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2010

ABSTRACT

EFFECT OF LOW AND HIGH- KINETIC ENERGY WETTING ON QUALITY OF SEDIMENT PRODUCED BY INTERRILL EROSION

Raindrop kinetic energy and sheet flow can disintegrate aggregates during interrill erosion, a process responsible for non point source pollution. Also, the dissolution process during aggregate wetting can affect interrill erosion. These factors can be responsible for changes in particle size distribution in the sediment, especially when different tillage systems are compared. The effect of soil tillage and management on soil properties is not uniform, which determine a wide range of runoff and sediment delivery rate. Variety in these rates can be associated with pore functions and their interactions with aggregate stability. One of the objectives of this study was to analyze the wetting behavior of soil aggregates from soils under conventional tillage compared with soils under no tillage. It was expected that the wetting rate is a function of pore system and that different tillage systems would affect the soil wetting behavior based on their impact on soil structure and shape. The second objective was to analyze the relationships among soil wetting rate, particle movement, organic carbon (OC) and iron release with the sediment produced via interrill erosion. A rainfall simulation experiment was performed in the field to determine the effect of low and fast soil wetting on total soil loss through high and low kinetic rainfall energy, sediment particle size distribution and OC loss. Two soils that differed in soil textural composition and that were under conventional and no tillage were investigated. Soil loss depended largely on soil characteristics and wetting rate. Particle size distribution of sediment was changed by treatment and the proportion of particles smaller than 0.053 mm increased over time, at any kinetic energy wetting level. Temporal OC and iron release were constant, which required a continuous source principally due to aggregate slaking. An empirical model was proposed to improve an interrill erosion equation by using a bond-dissolution mechanism that identified soil as a regulator of particle release.

Keywords: Iron and OC enrichment ratio; sediment particle size; soil wetting rate; tillage systems; interrill erosion.

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EFFECT OF LOW AND HIGH- KINETIC ENERGY WETTING ON QUALITY OF SEDIMENT PRODUCED BY INTERRILL EROSION

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To my wife, Mirta

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Section 1. INTRODUCTION

The movement of pollutants with sediments from unidentifiable origins is known as non-point source pollution. Rainfall provides the driving force for moving sediment at the land surface via water erosion processes. One of these processes, interrill erosion, is common in areas with low slope. Interrill erosion is very relevant for removing the smallest soil particles. Interrill erosion is defined as the process of detachment and transport of particles at the soil surface, that includes both i) splash-raindrop impact causing particle detachment and transport, as well as, ii) wash-shallow sheet flow causing also particle detachment and transport (Sharma et al., 1995; Laflen et al., 1997). Raindrop kinetic energy as well as fluid shearing during sheet flow are known to physically disaggregate soil during interrill erosion (Nearing, 1997). It is also known that as a soil aggregate is wetted, dissolution occurs and thus aggregate wetting affects interrill erosion.

Interrill erosion depends upon soil management and tillage. Specifically, soil surface cover and soil stability vary for different tillage systems, which in turn affect soil detachment during erosion. No tillage and moldboard plowing are tillage management systems, which strongly differ with regard to soil surface cover and in their influence on soil stability.

No tillage is characterized by only little soil disturbance during planting and the maintenance of crop residues at the soil surface. Therefore, under no-tillage the direct impact caused by raindrops on the soil is minimized. The protection of the surface through residues triggers low kinetic energy wetting. In contrast, the disturbing impact of moldboard plowing establishes a bare soil surface that determines a lack of protection against the rainfall. In this case, the soil surface is subject to direct impact of raindrops, thus the soil is exposed to a high kinetic energy wetting. Consequently, the disintegration of soil aggregates and subsequent sediment production occurs at a rate mainly affected by the two extremes of high kinetic energy wetting of bare soil, and low kinetic energy wetting of covered soil.

This study was conducted to analyze the consequences of two different ways of soil wetting, causing the disintegration of soil aggregates and the release of clay-silt sized particles in the sediment. Because sediment pollution has both physical and chemical dimensions, the movement of organic carbon and extractable iron in association with clay-silt sized particles, was also studied. The rationale for focusing on clay-silt sized particles was based on the observation that these fractions are the most important carrier of pollutants in overland flow. Iron and organic carbon are extremely important in maintaining soil stability and they are themselves pollutants. In addition, organic carbon sequestration by soil is an important strategy for mitigating atmospheric carbon dioxide concentration, but it is necessary to quantify the magnitude of organic carbon mobilization from the soil surface in order to improve this strategy.

In Section 2 details on the methods used to analyze the effects of wetting rate energy at the soil aggregate scale and at the field scale are provided. This section also describes the instruments used and the field plots treatments, as well as how the sediment was collected and analyzed with respect to its organic carbon and extractable iron enrichment ratios.

In Section 3, the two soils investigated and the two respective tillage systems are characterized. An analysis of soil aggregate properties was also included, in order to evaluate the effect of the tillage system on soil properties at different scales.

Aggregate responses to different wetting rates are shown and explained in the Section 3. This section also includes results of the field scale experiment. The hydrologic response investigated in the field is quantified based on total soil loss and particle size distribution of the sediment. In addition, the effect of different kinetic energies during wetting on the sediment enrichment ratios in iron and in organic carbon is evaluated.

The most important findings of this study are discussed and interpreted in Section 4. Finally, in Section 5 summary and conclusions are provided, describing the larger implications of this study and suggesting future research needs.

1.2. Literature review

Pollution of lakes and rivers and organic carbon (OC) losses from croplands are nowadays very relevant issues. Some studies have shown that, in the Midwestern USA, 30 to 50% of the OC was lost with converting natural into agro-ecosystems (Lal, 2002). Because most of this OC was lost through water erosion (Lal, 2002) and colloids were recognized as carrier of pollutants (Seta and Karathanasis, 1996a; Laegdsmand et al., 2004; Schumacher et al., 2005), a strong link emerged between land use and water pollution. In spite of the importance of these issues, the interactions and mechanisms involved in soil aggregate breakdown and the release of clay-silt sized particles size are poorly understood.

The relationship between the soil wetting process and the aggregate breakdown is still insufficient understood. The more the aggregates are disintegrated, the more the colloids are released to overland flow (Kjaergaard et al., 2004a). Relatively high and uniform soil wettability, defined as the opposite of water repellency, is a desirable quality of soils, because water repellent zones prevent rapid and uniform soil wetting and could affect crop growth (Ball et al., 1997; Eynard et al., 2004).

Wettability can be measured as a wetting rate, which is affected by organic and mineral composition of soil surfaces which can be rather hydrophilic and hydrophobic (Czarnes et al., 2000; Blanco-Canqui et al., 2007; Wuddivira et al., 2009) and by the structural arrangement of soil components (solids and pores) (Aluko and Koolen, 2001). At a molecular level, composition of solid surface-exposed hydrophilic or hydrophobic chemical groups and their packing density determine wettability (Leelamanie and Karube, 2007; Matthews et al., 2008). At a soil aggregate level, composition of soil and aggregate structure, defined as the spatial distribution of soil particles and pores determine wettability (Lado et al., 2004; Dexter et al., 2008).

The role of wettability in surface runoff is contradictory, because on one hand, the lack of soil wettability enhances water runoff and surface erosion (Hallett, 2001; Abu-Hamdeh et al., 2006; Leighton-Boyce et al., 2007). On the other hand, water repellency may stabilize soil against slaking and aggregate breakdown to some degree (Leighton-Boyce et al., 2007).

Disintegration of soil aggregates by water may result from a variety of physical and physicochemical mechanisms. Four main mechanisms have been identified (Fan et al., 2008): (i) slaking, i.e., breakdown caused by compression of entrapped air during fast wetting (Urbanek et al., 2007; Zaher and Caron, 2008); (ii) breakdown by differential swelling during fast wetting (Shainberg et al., 2003; Lado et al., 2004; Seguel and Horn, 2006); (iii) breakdown by the impact of raindrops (Ramos et al., 2003; Le Bissonnais et al., 2005; Issa et al., 2006) and (iv) physicochemical dispersion caused by osmotic stress due to wetting with low-electrolyte water (Mamedov et al., 2002; Keren and Ben-Hur, 2003; Mojid and Cho, 2008).

The relative role these mechanisms play in aggregate breakdown depends on the energy involved. Some studies tried to explain the relationships between disintegration of aggregates and infiltration rate or total soil loss (Lado et al., 2004; Blanco-Canqui and Lal, 2007; Ben-Hur and Lado, 2008). Lado et al. (2004) tested soils with three different clay contents (230, 410 and 620 g kg^{-1}), pre-wetted them with a low and a fast procedure and observed a significant decrease in infiltration rate only in soils with 620 g kg^{-1} of clay content. They attributed this behavior to the different aggregate stability among soils.

Wetting of soil aggregates weakened the cementing forces between particles inside the aggregate and caused aggregate breakdown (Rasiah and Kay, 1995; Ghezzehei and Or, 2000). In addition, Lado et al.(2004) observed that exposing air-dry soil aggregates to high intensity rain caused more severe aggregate breakdown than soil aggregates wetted with a slow rate before exposing them to high intensity rain. Ben-Hur and Lado (2008) suggested that these results could be related to the soil clay content. Blanco-Canqui et al. (2007b) found, in a long-term management system that the aggregate disintegration observed in a water erosion experiment was highly related to the wetting rate, and the soil organic carbon explained 48% of the variability in aggregate disintegration. The soils used in this study had 153 g kg^{-1} of clay content (Blanco-Canqui et al., 2007). At low soil clay content, the relationship between soil wetting and aggregate disintegration caused by water erosion has been controversial and not properly understood.

Contrasting results observed in several studies of soil structural stability and wettability could be due to the different quality of soil organic matter. Different organic components play specific roles in the wettability behavior (Eynard et al., 2006; Leelamanie and Karube, 2007; Urbanek et al., 2007). For example, hydrophobic organic constituents, like aliphatic molecules, determine soil water repellency (Dinel et al., 1998; Horne and McIntosh, 2000), while hydrophilic organic constituents can interact with water when the soil is wet and with each other when the soil is dry. Those kinds of interactions could be responsible for changes in aggregate water stability, and can modify soil function, especially when different tillage systems are compared.

Several studies have shown that tillage systems modified the organic carbon content in aggregates (Cambardella and Elliott, 1992; Cambardella and Elliott, 1993b; Blanco-Canqui et al., 2004). Also, tillage systems differ in the way they produce a seedbed and how the crop residues are incorporated into the soil surface (Alvaro-Fuentes et al., 2008a).

It is a fact that tillage systems that use moldboard plowing tend to reduce the soil aggregate size when compared to reduced tillage or no tillage systems (Perfect et al., 1997; Blanco-Canqui and Lal, 2007; Pikul et al., 2007). It is also a fact that using moldboard plow and subsequent disc produces a bare soil surface. This last condition exposes soils to a high kinetic energy-wetting process under rainfall. Thus, the wetting process will affect the sediment production in soils under moldboard tillage. Although no-tillage systems maintain the soil surface covered with residues, which improves many soil functions, the effect on aggregate stability remains controversial. In a study with different soil textures, a large water aggregate stability under NT compared with CT was found, but only with finer-textured soils in humid conditions (Buschiazzo et al., 1998). Conversely, other studies were not able to find differences in aggregate stability in sandy loam and silt loam soils, suggesting that long-term soybean monoculture could be responsible for this situation (Micucci and Taboada, 2006). The reason for this behavior could be that soybean residue compared to corn residue has a low concentrations of phenol components and also the return of biomass to the soil is very low (Martens, 2000). However, it is a fact that soil surface cover causes a low kinetic energy–wetting process under rainfall, and reduces sediment production compared to conventional tillage.

The response of transport behavior to a soil tillage and management is not unique. Untilled compared to tilled soil caused great (Frebairn et al., 1986; Kay and

VandenBygaart, 2002; Wairiu and Lal, 2006) similar (Ankeny et al., 1990) or low water infiltration rates (Gantzer and Blake, 1978; Gomez et al., 1999; Rasmussen, 1999). The way in which differences in total porosity are associated with differences in pore size distribution, depended on soil type and tillage. Under identical site conditions, NT compared to CT resulted in a lower macro-pore volume (>30 µm) on sandy soil and silt loam, whereas the opposite effect was found on sandy loam (Schjonning and Rasmussen, 2000).

The water infiltration rate influences the runoff rate and the total soil loss. Interrill erosion depends on the kinetic energy of rainfall and by definition is the predominant erosion process in low slope landscapes (Foster et al., 1981; Meyer, 1981; Meyer and Harmon, 1989). Interrill erosion is highly selective with respect to particle sizes (Foster et al., 1981; Hairsine and Rose, 1991; Nearing et al., 2005). In addition, interrill erosion is a time-dependent process (Wan and El-Swaify, 1998a; Boardman, 2006; Asadi et al., 2007b; Wang et al., 2007). Temporal variability in the sediment concentration suggested a possibility of very low transport capacity of the overland flow at field scale erosion in a sandy soil (Issa et al., 2006). They commented that the change in soil surface seal was responsible for this variability. However, it was commented that despite all evidences to the contrary, aggregate stability and soil erodibility, i.e. how easily the soils are eroded (Renard et al., 1997), are commonly considered constant properties (Vermang et al., 2009). Furthermore, some predictive models still do not take into account that aggregate stability and soil erodibility are influenced by several time-dependent parameters, such as antecedent water content, wetting mode and soil organic carbon content (Abrahams et al., 2000; Walker et al., 2007). In some studies an increase in aggregate stability and reduced soil loss with increasing antecedent water content were found (Truman et al., 2007; Vermang et al., 2009), whereas the opposite behavior was also found (Rejman and Usowicz, 2002). Thus, the relationships among soil wetting, aggregate stability and soil loss are still not well understood.

The soil aggregate disintegration process is a key in the release and movement of different particle sizes in overland flow (Proffitt et al., 1993; Wan and El-Swaify, 1998a; Zhang et al., 2003). In addition, the range of particles smaller than 0.053 mm in diameter has an enormous potential to mobilize different elements, especially when they are linked with OC (Wan and El-Swaify, 1998b; Quinton et al., 2001; Schiettecatte et al., 2008b). Hence, OC is mobilized in the overland flow (Starr et al., 2000; Kingery et al., 2002; Bertol et al., 2005), but it is not well understood how this mobilization occurs. The enrichment ratio in OC was introduced as an index to establish OC contribution in runoff-sediment to non-point source pollution. This index is the ratio of OC concentration in sediment particles and the OC concentration in the same particle size class from the original soil prior to runoff (Wan and El-Swaify, 1998b). The enrichment ratio in OC differed due to several factors, such as soil texture, OC content, runoff rate and soil loss but still it is not clear why (Wan and El-Swaify, 1998b; Schiettecatte et al., 2008a). The quantity and the way in which OC is transported by overland flow under different tillage systems are still not well-understood key relationships (Lal, 1998; Lal and Pimentel, 2008) relevant for C balance in cropland areas.

Another relevant process related to interrill erosion is the mobilization of micronutrients, e.g. iron, and its potential risk for both, water pollution and soil stability. Several studies have shown that iron can easily be removed in overland flow coupled with OC and selenite (Rhoton et al., 2003; Maloney et al., 2005; Coppin et al., 2009) , but values of sediment enrichment ratio in iron have not been quantified, yet.

1.3. Objectives

In brief, the objectives of this study were:

a) To understand if the wetting behavior of aggregates evaluated with different procedures differs between conventional tillage and no tillage,

b) to determine relationships between aggregate parameters that can explain the breakdown behavior of aggregates with respect to the wetting rate,

c) to study changes in the particle size distribution in the sediment, when soils are exposed to low and high-kinetic energy wetting,

d) to analyze how OC and iron content in the sediment vary under low- and high-kinetic energy wetting, and

e) to understand how the enrichment ratio in OC and iron differ in the finest particles in sediment produced by low and high kinetic energy wetting.

The assumption underlying the first objective is that the wetting rate is a function of pore stability and under conventional tillage of decrease in organic carbon and exchangeable cations contents. The hypothesis is that the water content of an aggregate at the time of rupture and the time period until rupture are different depending on the wetting mode and the tillage system. The hypothesis to test in accordance with the second objective is that low-energy wetting produces a high release of the smallest particles in the sediment, compared to the effect of high-energy wetting.

The hypothesis that relates to the third and fourth objectives are that the OC in different particle size classes depends on the initial content of OC in the particles considered and an additional gain in organic carbon in the transport process. During the process of rupture and transport of different particles, the organic carbon is released from different exposed sites. The amount of exposed sites depends on the interaction between the wetting rate and the kinetic energy of the rainfall. The higher the kinetic energy involved, the higher the aggregate disintegration which increases the probability that OC and iron can be adsorbed by particles released in the overland flow, causing the respective enrichment ratios to be larger than 1.

Section 2. MATERIALS AND METHODS

This study was performed in two experimental sites. One site was Plot 66 at the Experimental Farm Spindletop of the Agricultural Experiment Station, University of Kentucky, Lexington, KY. The soil was classified as a Maury silt loam soil and is grown with corn since 15 years. The other site was located in a farmer's field in Owensboro, Davies County, KY. This soil belongs to the Calloway series and was classified as an Aquic Fragiudult silt soil. Since 5 years, this soil has been managed in a soybean/corn/tobacco rotation. At both sites, two tillage systems, i.e., No tillage (NT), and Conventional tillage (CT), using moldboard plow and disc, were investigated.

2.1. Methods to evaluate soil physical, chemical and biological properties

At each site, soil samples were taken from 0 to 5 cm depth with five replicates. The samples were air-dried in the greenhouse. Total organic carbon (TOC) concentration was measured by dry combustion. Exchangeable Ca, Mg, Na, and K were determined with a Flame atomic absorption spectrophotometer (FAAS). Oxalate-extractable Fe (Fe_{Ox}) (McKeague and Day, 1966) was measured with FAAS as well. Particulate organic matter (POM-C) content was determined with a sodium extraction procedure (Mirsky et al., 2008). For this purpose, 10 g of air-dried soil were disintegrated with NaOH overnight, and washed with distilled water through a 0.053 mm sieve. The remaining material in the sieve consisting of sand particles and POM-C was dried in an oven at 60 ºC, weighed, crushed and burned in a muffle oven at 560 °C and the POM-C was determined by weight difference.

Electrical conductivity (EC) and pH in the soil samples were measured using a potentiometer. Cation exchange capacity was measured by displacement with NH_4 Acetate. Soil texture was determined by the pipette method (Gee and Bauder, 1986). Mean weight diameter (MWD) and geometric mean diameter (GMD) of aggregates smaller than 0.053 to 10 mm were determined from the dry aggregate size distribution (Kemper and Rosenau, 1986). Dry sieving was performed with a Fritsch vertical vibratory sieve shaker for 30 s using oscillation amplitude of 2 mm and a frequency of approximately 50 Hz.

Water stable aggregates (WSA) in size classes from 2 to 1 mm in diameter were measured with a wet sieving apparatus, by following the procedure of Kemper and Rosenau (1986). In addition, water stable aggregates (WSA) in size classes from 10 to 8 mm, 8 to 4.75 mm and 4.75 to 2.78 mm were also measured with the same wet sieving apparatus. Water dispersible colloids (WDC) were measured according to the procedure described in (Seta and Karathanasis, 1996b).

In order to calculate aggregate shape factors, three axes (Figure 2.1) were measured with a caliper, before the wetting rate test was performed. These indices were:

- Shape factor (*SF*) (McNown and Malaika, 1950)

$$SF = \frac{c}{\sqrt{(ab)}} \qquad (1)$$

- Flatness ratio (*Fr*)

$$Fr = \frac{a}{b} \qquad (2)$$

- Elongation ratio (*El*)

$$El = \frac{c}{a} \qquad (3)$$

- Sphericity (*S*)

$$S = \frac{\text{surface area of equivalent sphere}}{\text{actual surface area}} \qquad (4)$$

- Circularity (*C*)

$$C = \frac{\text{circumference of circle with the same area}}{\text{actual perimeter}} \qquad (5)$$

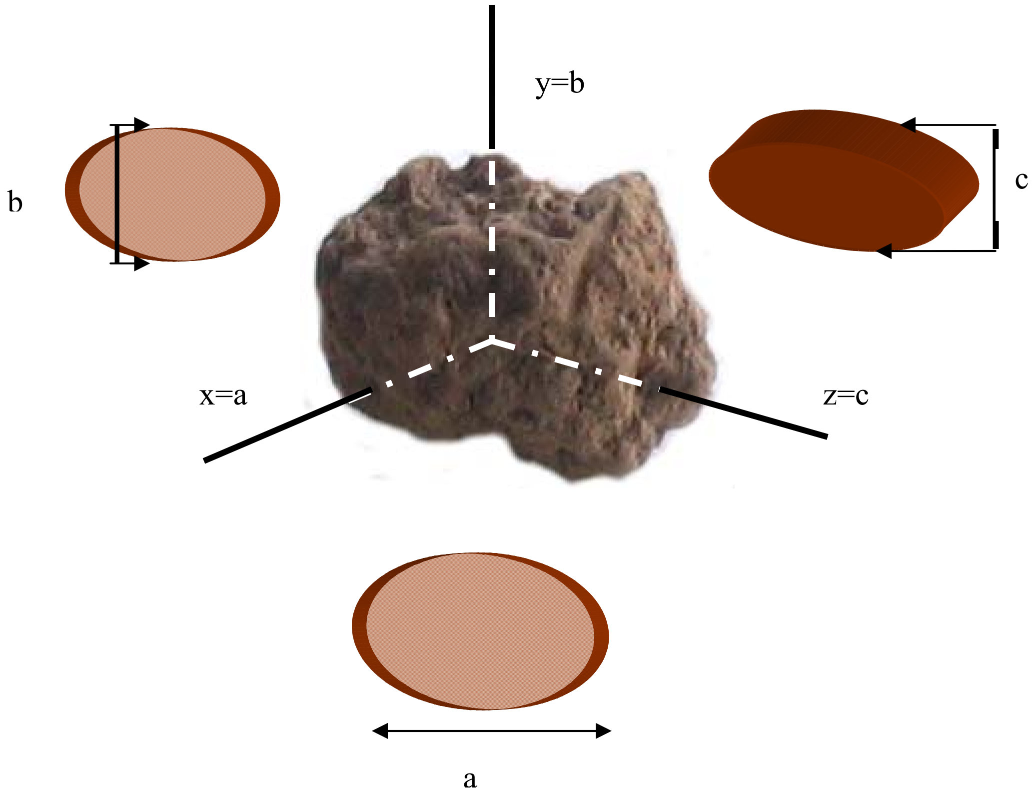


Figure 2.1: Axes measured in soil aggregates, with a scheme of the different values used to calculate the indexes: a= length; b= height; c= width.

- Rugosity (R)

$$R = \frac{Actual\ \ perimeter}{Circumference\ \ of\ \ circumscribing\ \ circle} \qquad (6)$$

Particle density (ρ_s) was determined with the pycnometer method; aggregate density was quantified based on the spheroid formula yielding the volume and the oven dry weight. Total porosity of aggregates (ϕ) was calculated with the following equation:

$$\phi = 1 - \frac{\rho_{ag}}{\rho_s} \qquad (7)$$

where ρ_{ag} is aggregate density.

Wetting rate, as proposed by Rasiah and Kay (1995), was calculated with the first order rate equation proposed by them:

$$\theta(t) = \theta_0 + \Delta\theta_m \left(1 - e^{-kt}\right) \qquad (8)$$

where $\theta(t)$ is total water content, θ_0 is the initial aggregate water content, $\Delta\theta_m$ is the change in water content, t is time and k is the first-order wetting rate constant.

2.2. Methods to evaluate the wetting rate at the aggregate scale

In order to determine the aggregate wetting rate, three sizes of aggregates were used: 8 mm (±0.787), 4.75 (±0.493) mm and 2.78 (±0.35) mm in size, from both soils and tillage systems selected for this study. To select these sizes, aggregate samples were sieved in a battery of sieves. For example, aggregates of 8 mm were selected by hand from the range from 10 to 8 mm, when they were visually representative of the lowest size in this range. For convenience, aggregate sizes used in this experiment were labeled as: 8 mm, 4.75 mm and 2.78 mm, respectively. Two procedures causing different wetting rates were performed to evaluate the wetting behavior of these aggregates:

a) In the first procedure, aggregates were placed on a porous plate and wetted slowly by capillary rise (Eynard et al., 2004; Eynard et al., 2006). In this experiment, the water uptake of an aggregate was read at each minute through the movement of the meniscus in a horizontal capillary of known diameter.

These readings were converted to a wetting rate. The porous plate was covered with a cup to minimize evaporative water loses.

b) In the second procedure, aggregates were wetted under kinetic impact with a single drop former. The drop former was fixed at 1 meter height above the aggregate and produced a drop of 1.5 mm in diameter with a weight of approximately 0.02 g. Drops fell on the aggregates at one-second intervals. A mesh was placed under the aggregate to maintain it in position and to allow free drainage of excess water subsequent to the impact. The total aggregate mass was recorded on a balance in fixed intervals of 1 to 5 impacts. Based on preceding observations, the last mass value was recorded at five impacts being the limit before the aggregate's rupture. Thirty aggregates of each size were used to measure water content and time to rupture in both tillage systems at each site. A detail of these devices use is shown in Figure 2.2.

2.3. Methods to evaluate particle release from aggregates with and without shaking in water

To explore the effect of different energy levels on the wetting rate, a modified wet sieving procedure was performed with a wet sieving apparatus. Aggregates from both soils and tillage systems that were in the range from 10 to 8 mm, 8 to 4.75 mm and 4.75 to 2.78 mm size were studied. In brief, 40 g of aggregates of each range were placed in containers with a bottom mesh of 0.250 mm width and located in a wet sieving apparatus. To simulate low kinetic energy wetting, aggregates were simply submerged in water for 1 h without shaking (Nsh). The containers with water and particles released were removed every 5 minutes, and were replaced for others containers with clean water. To simulate high kinetic energy wetting, aggregates were shaken (Sh) as described by Kemper and Rosenau (1986) for water stable aggregates. However, this procedure was modified by using only water and the aggregates were shaken for 1 h. As for the low kinetic energy wetting, containers with water and particles released were removed every 5 minutes, and replaced with new containers with water. Particles released were poured through a battery of sieves (0.105 mm, 0.053 mm and a bowl to capture particles smaller than 0.053 mm), oven-dried at 105°C and weighed.

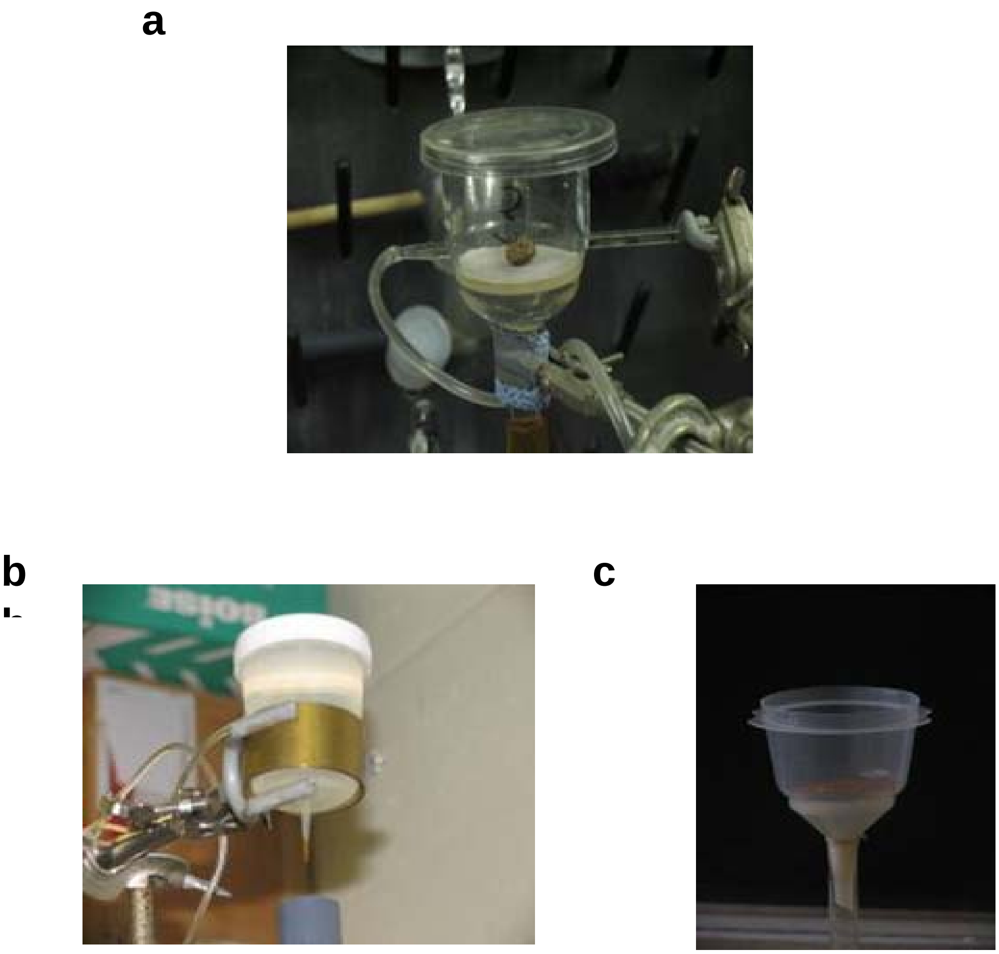


Figure 2.2: Different devices to measure wetting rate. a) Tension table; b) Drop former; c) Splash-guard cup with a mesh to provide free drainage.

2.4. Methods to evaluate hydrologic response and sediment production under high and low kinetic energy wetting at the field scale

To test the hydrologic response and sediment production under high and low-energy wetting in the field, the experimental sites were exposed to a simulated rainfall. A nozzle-type rain simulator was used to produce a rainfall of 87.5 mm/h for the duration of one hour. Prior to the 1-hour-long rainfall simulation, the soils were irrigated for ten minutes with high and low kinetic energy, respectively, to simulate the situation of low and high initial kinetic energy- wetting of the soil surface. A resting interval of five minutes was established before the main rainfall simulation. The duration and intensity of rainfall were selected by experience gained in order to produce enough overland flow and sediment to perform the subsequent laboratory analysis of the sediment.

For high kinetic energy wetting, the rainfall reached the bare soil surface. For low kinetic energy wetting the soil surface was covered with four layers of plastic mesh in order to avoid the effect of drop impact (Figure 2.3).

During rainfall simulation, water and sediment were collected at the beginning after a 2-minute interval, followed by a 3-minute interval to identify the initial effect of the respective wetting method and then, at every five minutes until the end of the experiment at one hour after the beginning of the rainfall simulation.

Sediment collected was poured through a battery of sieves of 0.500 mm, 0.250 mm, 0.100 mm, 0.053 mm and a bowl to capture all fractions smaller than 0.053 mm. All particles collected were oven dried at 60 ºC and weighed.

The battery of sieves was selected according the ARS-USDA standard procedures (Miller and Baharuddin, 1987; Elliot et al., 1989) to allow for comparison with data published in the literature (Wan and El-Swaify, 1998a; Marquez et al., 2004; Polyakov and Lal, 2008).

Runoff volume was determined for each sample gravimetrically using the difference between the weight of the total sample and the weight of the dried bottle and sediment. Runoff and sedimentation rates were determined for each sample interval by dividing respective weights by the sampling duration.

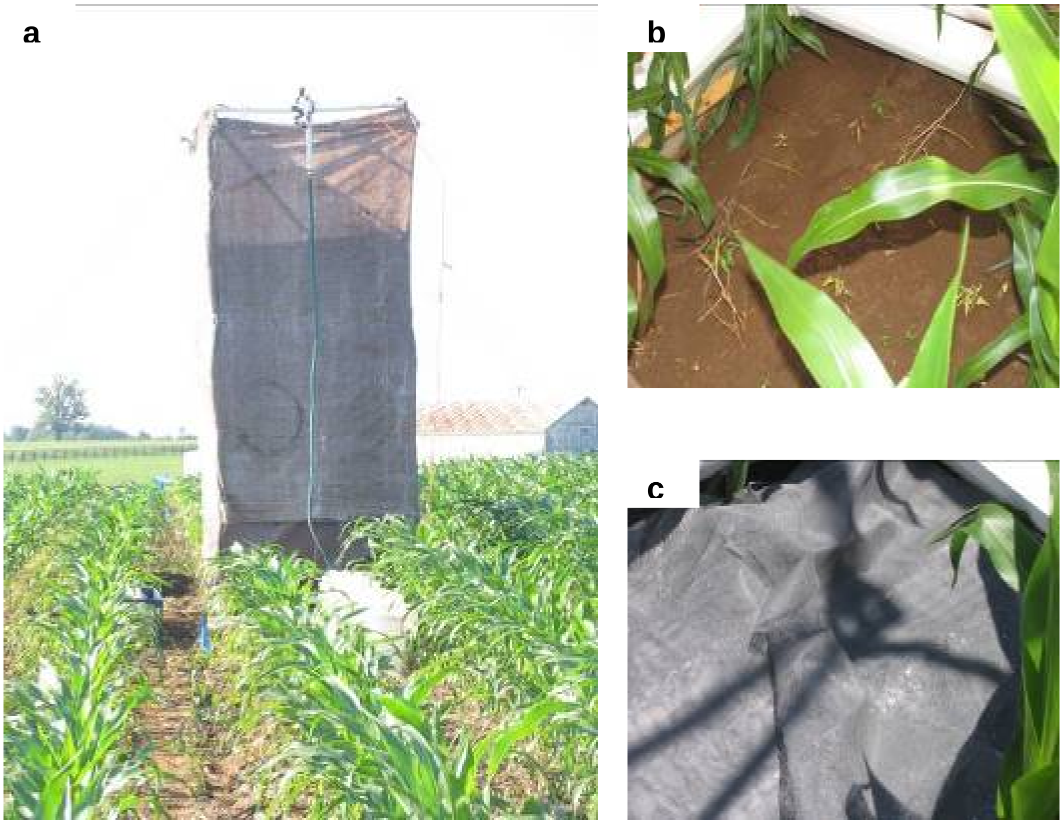


Figure 2.3: Rainfall simulator and field plots. a) Nozzle-type rain simulator. b) High kinetic energy wetting plot. c) Low kinetic energy wetting plot, with plastic mesh.

Total organic carbon (TOC) was measured by combustion of all particle size in the sediment. Enrichment ratio of organic carbon (ER_{OC}) was determined by the following equation (Wan and El-Swaify, 1998b):

$$ER_{OC} = \frac{m_{xi}}{M_{x0}} \qquad (9)$$

where m is the concentration of total organic carbon (g kg^{-1}) in the particle from the sediment (x_i) and M is the concentration of total organic carbon (g kg^{-1}) in the same particle size class from the soil surface before the rainfall (x_0). In the same way, enrichment ratio in iron (ER_{Fe}) (eq. 10) was calculated by using the $Fe_{(ox)}$ concentration in the particles from the sediment (mg kg^{-1}) and in the particles of the same size at the soil surface before the rainfall.

$$ER_{Fe} = \frac{Fe_{sed<0.053}}{Fe_{Soil<0.053}} \qquad (10)$$

The sediment delivery rate (D_i) (g m^{-2} min^{-1}) in interrill erosion was calculated according to the Zhang formula (Zhang et al., 1998):

$$D_i = K_i I q^c S^{2/3} \qquad (11)$$

where K_i (g min^{-1} m^{-4}) is the erodibility parameter, I is rainfall (m min^{-1}), q (m^3 min^{-1}) is the unit discharge, S (m m^{-1}) is the slope and c is the exponential coefficient used to fit experimental data.

The organic carbon delivery rate (OC_{DR}), which represents the OC effectively delivered from the soil was calculated through the following formula:

$$OC_{DR} = TOC_{sed<0.053} x\ D_{i\ sed<0.053} \qquad (12)$$

where OC_{DR} is in g C m^{-2} min^{-1}, $TOC_{\text{sed} < 0.053}$ is total organic carbon content in particles smaller than 0.053 mm in the sediment in g g^{-1} and $D_{i\ \text{sed} < 0.053}$ is sediment delivery rate of particles smaller than 0.053 mm, in g m^{-2} min^{-1}.

2.5. Statistical analysis

Data of soil parameters exposed to different tillage systems were statistically analyzed by using one way analysis of variance and mean comparison according to least mean differences. Relationships among selected soil parameters were explored with Pearsons correlation procedure, single regression and multiple stepwise regression analysis.

At aggregate scale, soil parameters were studied in a multifactor model 2 x 2 with interactions and n = 30. Soil, as main factor, represented soil characteristics of each soil considered in this study. Tillage, considered also a main source of variation, represented conventional and no tillage treatments.

Wetting rate and water content before the rupture with and without drop impact as well as data of particles released with and without shaking in water were analyzed in a multifactor model 3 x 2 x 2 with interactions. Soil, Tillage and Energy were considered main sources of variation. In this case, Energy represented with and without drop impact in the wetting rate experiment or with and without shaking in water to analyze particles released from different aggregate sizes.

Multiple range tests were used to compare means and Pearsons correlation procedure to explore the relationships among selected soil parameters, wetting rate and water content before the rupture.

At field scale, data collected in the rainfall simulation experiment were statistically analyzed in a multifactor model 2 x 2 x 2 with three replicates in the Maury silt loam soil and two replicates in the Calloway silt soil. Main sources of variation in this experiment were Soil, Tillage and Energy. In this case, Energy represented high and low kinetic energy wetting. One way analysis of variance and mean comparison according to least mean differences were used to study data produced at the same time period.

Repeated measures modeling as according to the Mixed procedure of SAS was used to perform statistical analysis when data of runoff and sediment release were related with time. In these cases, time was also considered as a source of variation.

Section 3. RESULTS

3.1. Effect of different tillage systems on selected physical, chemical and biological soil properties

3.1.1. Effect of tillage on selected soil physical and biological parameters

Selected properties of soils used in this study are shown in Table 3.1. The Maury silt loam soil has more clay and sand and less silt than the Calloway silt soil, according to soil texture analysis. The water stable aggregate index (WSA) is used to characterize the soil stability based on the resistance of aggregates against being destroyed by shaking in water (Kemper and Rosenau, 1986; Daraghmeh et al., 2009). This index shows that soils at both locations under NT do not significantly differ with respect to soil stability in spite of the soil textural differences (Table 3.1). In addition, soils under CT have lower stability than under NT, but the Maury silt loam soil under CT was the most unstable because its WSA value was the lowest (Table 3.1). This result could be a consequence of the longest period under aggressive tillage in the Maury soil.

The water dispersible colloid index (WDC) reflects how easily the soil can liberate colloids when exposed to water (Seta and Karathanasis, 1996b; Watts and Dexter, 1998). Table 3.1 shows that under CT the Maury soil was not different in WDC compared to NT ($p<0.05$). However, in the Calloway silt soil, WDC under CT was higher than WDC under NT ($p<0.05$).

Dry aggregate size distribution (DASD) was used to characterize the tillage system (Kemper and Rosenau, 1986) (Figures 3.1 and 3.2). DASD is useful in combination with the geometric mean diameter (GMD) and mean weight diameter (MWD) to analyze the effect of tillage systems on soil structure because it gives information about how the GMD or MWD are composed (Braunack and Dexter, 1989).

DASD measured in the Maury silt loam soil under CT and NT showed that 50% was dominated by aggregates smaller than 3 mm in diameter. Half of this percentage was

Table 3.1: Selected soil properties of the Maury silt loam soil and the Calloway silt soil used in this study.

Soil	Tillage	Sand (%)	Silt (%)	Clay (%)	TOC (g kg^{-1})	POM-C (g kg^{-1})	Fe(ox) (mg kg^{-1})	GMD (mm)	MWD (mm)	WSA (% higher than 0.25 mm)	WDC (g kg^{-1})
Maury	CT	8.4	65.2	26.4	11.1b	5.2d	37.4c	3.3b	4.2b	75a	32.60c
	NT	8.7	67.4	23.9	19.6c	15.2b	37.1c	3.4c	4.4c	96c	28.01c
Calloway	CT	4.8	83.9	11.3	9.4a	2.8c	15.1b	2.9a	2.7a	81b	12.50b
	NT	5.2	81.6	13.2	12.6b	8.9a	7.8a	3.2b	3.9b	91c	8.60a

Abbreviations: CT= conventional tillage; NT= no tillage; TOC= total organic carbon; POM-C= particulate organic matter; $Fe_{(ox)}$ = oxa;ate extractable iron; GMD=geometric mean diameter; MWD= mean weight diameter; WSA= water stable aggregates; WDC= water dispersible colloids. Different letter in the same column means significant with $p<0.05$ according with the LSD test.

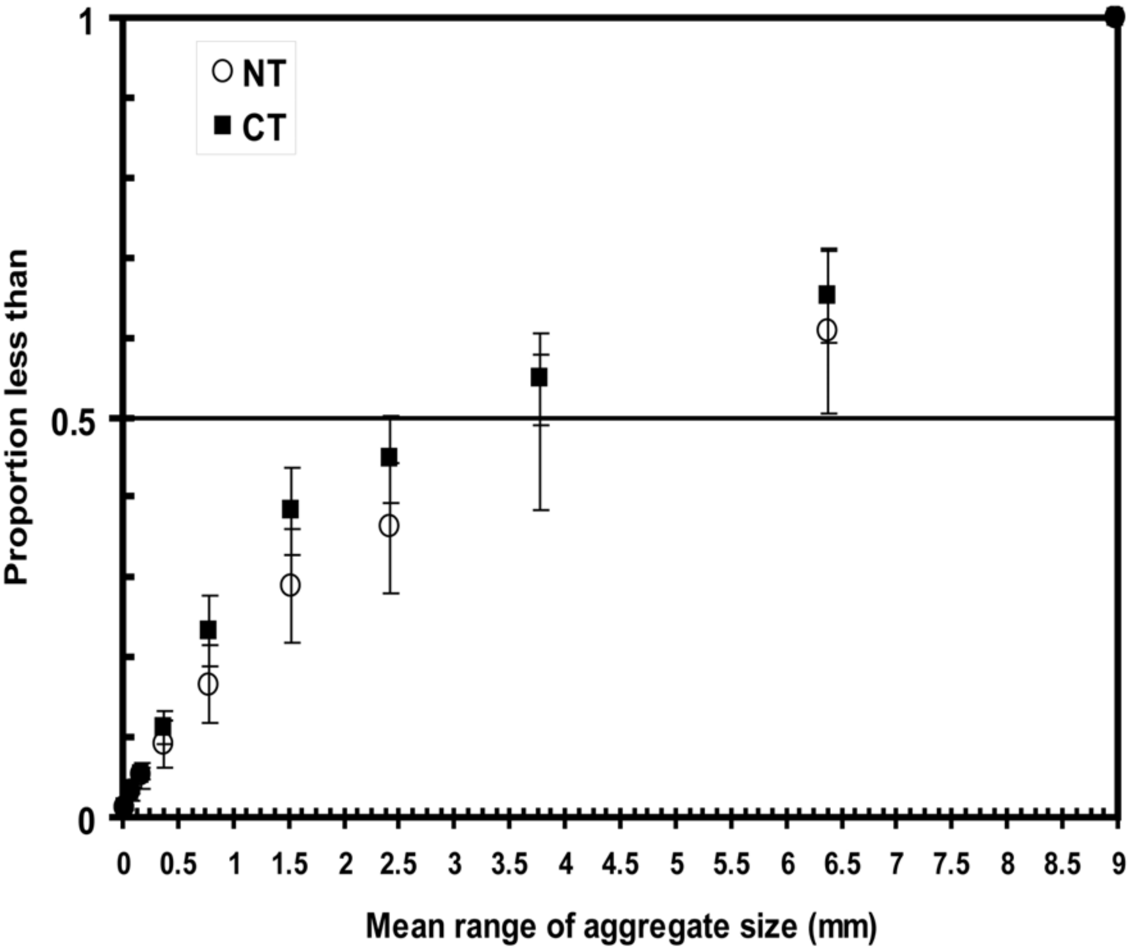


Figure 3.1: Dry aggregate size distribution (DASD) in the Maury silt loam soil under both, conventional (CT) and no tillage (NT).

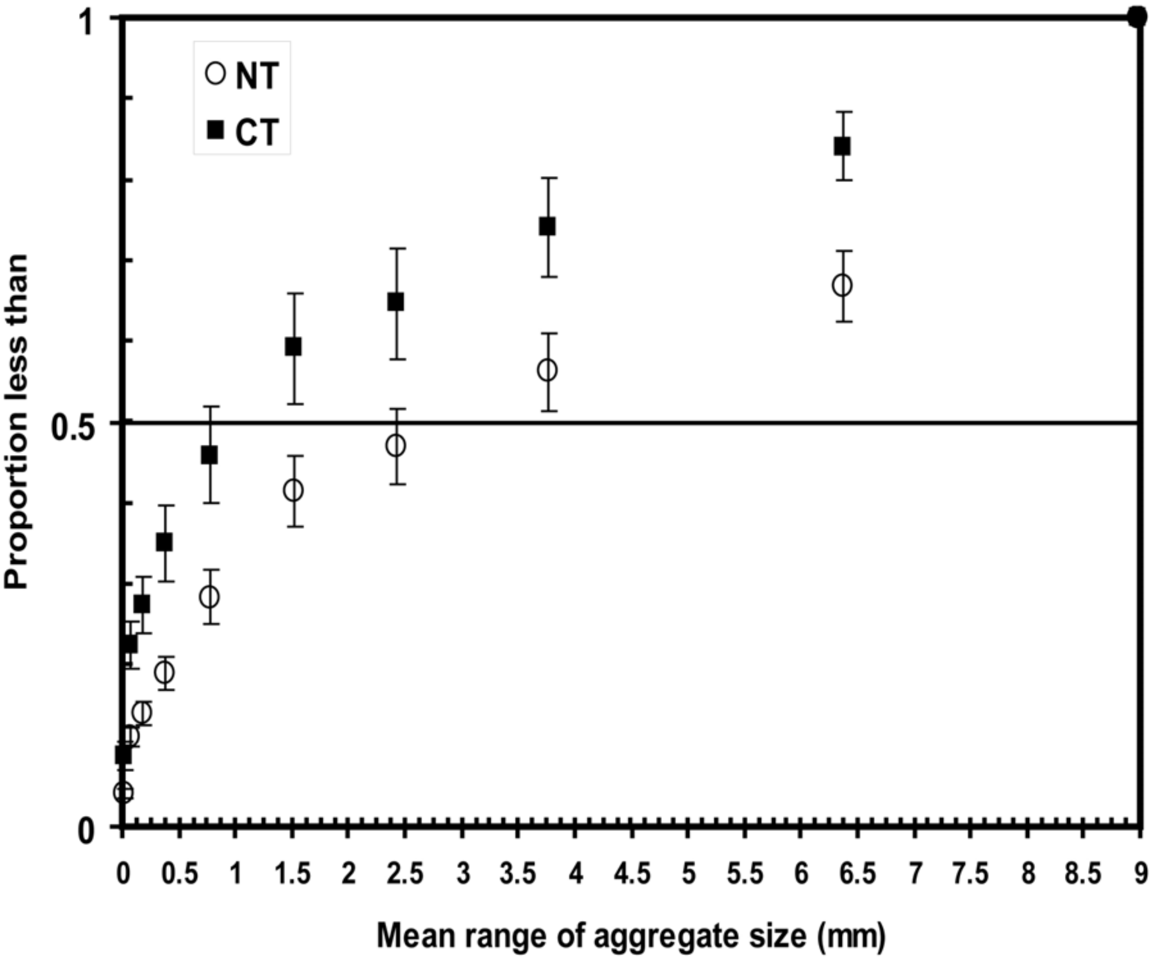


Figure 3.2: Dry aggregate size distribution (DASD) in the Calloway silt under both, conventional (CT) and no tillage (NT).

completed with aggregates smaller than 1 mm (Figure 3.1). According to Figure 3.1, DASD is similar in both tillage systems in the Maury silt loam soil, which means that the contrasting tillage did not cause differences in the aggregate size distribution.

On the other hand, in the Calloway soil, CT reduced the aggregate size distribution compared with NT. Under CT (Figure 3.2), 50 % of dry aggregates was dominated by the fraction smaller than 1 mm and half of this percentage were aggregates smaller than 0.25 mm. Nevertheless, the cumulative particle size distribution curve for NT (Figure 3.2) showed that 50% of DASD were aggregates smaller than 3 mm. Half of this percentage was filled with aggregates smaller than 1 mm.

Values of MWD (Table 3.1) showed that the Calloway soil under CT yielded the smallest value of MWD ($p<0.05$), which was significantly different with the value found under NT on the same site. The Maury soil under NT had the highest MWD value. The MWD index has a bias toward the large aggregates (Van Bavel, 1949). For this reason, any aggregate size distribution with larger aggregates than others has high values of MWD, as occurs with the Maury soil under NT. Geometric mean diameter (GMD) has the opposite bias, and unlike MWD this index emphasizes the amount of small soil aggregates. Notice the low values in the Maury soil under NT comparing GMD with MWD, and the high values measured in the Calloway soil under CT (Table 3.1). The higher the difference between MWD and GMD, the higher the proportion of large aggregates in the soil.

As expected from the aggregate size distribution (Figures 3.1 and 3.2), the Calloway soil under CT had the lowest GMD value ($p<0.05$) and the Maury soil under NT had the highest (Table 3.1). At the same time, no difference was observed between the Calloway soil under NT and the Maury soil under CT. Values of MWD (Table 3.1) showed that under CT the Calloway soil yielded the smallest value of MWD ($p<0.05$), which had significant differences to the value of the Calloway soil under NT. The Maury soil under NT had the highest MWD value.

This lack of difference under contrasting tillage systems could be related with the high percentage in silt content in the Calloway soil (Table 3.1), which determines a natural structural weakness of the aggregates (Towner, 1988). This structural weakness could have prevented the persistence of large aggregates in silt soils under tillage (Dexter, 1988; Unger et al., 1991). Another reason could be the short period under NT in the Calloway soil compared with the long period under NT in the Maury soil, i.e., a long period of time with no tillage could allows further development of organic components that contribute to increase the aggregation process (Angers et al., 1995; Abiven et al., 2007)

Total soil organic carbon (TOC) was higher under NT than under CT in both soils (Table 3.1), but the difference between NT and CT was larger in the Maury soil than in the Calloway soil. Despite the large differences in silt and clay content in our soils (Table 3.1), the amount of TOC was higher under NT than under CT. In addition, under CT both soils have similar low values of TOC, but the reason for this behavior is not clear. Probably, the different periods of tillage in both soils and the crop rotations could be responsible for this finding.

Data of particulate organic matter (POM-C) in the Maury and Calloway soil under different tillage systems are included in Table 3.1. Under NT, the soils had more POM-C than under CT. However, the Maury silt loam soil had more POM-C than the Calloway silt soil, which means that soil texture was an important variable to consider. One reason could be the nature of silt particles, which have no or very low capacity to build bonds with OC.

Relationships among those selected soil parameters from Table 3.1 were explored through Pearson correlation analysis (Table 3.2). Close relationships observed among our TOC, GMD and MWD data suggest that TOC could be an important soil aggregation factor. However, we found no relationship between TOC and WSA, which is a measurement of aggregate stability in water. No relationship observed among TOC, WDC (the amount of free colloids) and clay content (Table 3.2) could suggest that only a specific form of OC could be associated with clay particles to build aggregates.

A multiple stepwise regression analysis was used to explore the importance of TOC and POM-C as aggregation factors in these soils. Values of WSA and WDC were the dependent variables and several parameters including TOC, POM-C and clay content were the independent variables. Only significant results were included in Tables 3.3 and

Table 3.2: Pearson correlations among selected soil parameters measured in the Maury silt loam and the Calloway silt soil.

	TOC	Sand	Silt	Clay	WSA	GMD	MWD	WDC
Sand	0.60 (NS)	1						
Silt	-0.50 (NS)	-0.99 (***)	1					
Clay	0.44 (NS)	0.98 (***)	-0.99 (***)	1				
WSA	0.60 (NS)	0.27 (NS)	0.38 (NS)	0.41 (NS)	1			
GMD	0.69 (*)	0.84 (***)	-0.84 (***)	-0.84 (***)	-0.03 (NS)	1		
MWD	0.71 (*)	0.79 (**)	-0.79 (**)	0.78 (**)	0.04 (NS)	0.99 (***)	1	
WDC	0.095 (NS)	0.64 (*)	-0.62 (*)	0.61 (NS)	-0.49 (NS)	0.13 (NS)	0.03 (NS)	1

Abbreviations: TOC = Total organic carbon; WSA = Water stable aggregates; GMD = Geometric mean diameter; MWD= Mean weight diameter; WDC= Water dispersible colloids. (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001. NS = not significant ($\alpha > 0.05$); n=12.

Table 3.3: Stepwise regression analysis predicting among water stable aggregates (WSA), from total organic carbon (TOC) and clay content (Clay).

Parameter	Estimate	Standard Error	T statistic	p-value
Constant	0.70	0.0250	27.489	***
TOC	0.02	0.0019	12.090	***
Clay	-0.0004	0.0116	-6.936	**

Abbreviations: (**) significant at < 0.01: (***) significant at <0.001.

Table 3.4: Analysis of variance of the multiple regression models among water stable aggregates (WSA), total organic carbon (TOC) and clay content.

Source	Sums of squares	df	Mean Square	F-ratio	p-Value
Model	0.033	2	0.0160	31.19	**
Residual	0.002	5	0.0005		
Total (correg)	0.036	7			

R^2 = 92.6 percent; R^2 (adjusted for d.f.) = 89.6 percent; Standard Error of Estimate= 0.023; Mean absolute error = 0.016; Durbin-Watson statistic = 1.24 (P=0.0102). (**) significant at <0.001.

By combining TOC concentration in aggregates from 2 to 1 mm and clay content it is possible to explain the variability in WSA, according to the equation:

$$WSA = 0.70 + 0.02(TOC) - 0.0004(Clay) \quad (12)$$

where *TOC* = total organic carbon in g kg^{-1} and *Clay* is in g kg^{-1}.

Equation (12) explains 89 % of the variability in WSA. When particulate organic matter (POM-C) replaced TOC values, the new equation (Equation 13) explained 99% of the variability in WSA. POM-C is a proportion of the TOC content, and explained most of the variability in WSA. This finding suggests that POM-C was the principal factor influencing water aggregate stability in these soils.

$$WSA = 0.83 + 0.007(Clay) - 0.019(POM-C) \quad (13)$$

where *Clay* and *POM-C* are expressed in g kg^{-1}.

A multiple regression analysis performed for WDC instead of WSA showed that neither TOC nor POM-C were associated with the amount of free colloids in these soils. The best model found to explain the variation in WDC was a polynomial regression (Equation 14) that included only the silt plus clay content (Table 3.5), which explained about 82% of the variation in WDC ($p<0.05$) (Table 3.6). This suggests an important control of soil texture on the release of free clay in these soils. An analysis to explore the relationship among WDC, clay, silt content, TOC and Fe $_{(ox)}$ content, showed the influence of iron on WDC, because by using Fe $_{(ox)}$ content alone, it was possible to explain more than 60% of the variation in this soil parameter (Equation 15). However, Equation 13 could not improve the prediction by including Fe $_{(ox)}$, which suggests that the parameters tested had overlapping actions.

$$WDC = 32181.5 - 689.5(Silt\ plus\ Clay) + 3.693(Silt\ plus\ Clay)^2 \quad (14)$$

$$WDC = 6.897 + 0.7681(Fe) \quad (15)$$

One possible reason for this finding is that Fe oxides were themselves a component of the Silt + Clay fraction, thus Equation 14 already includes the effect of Fe.

Table 3.5: Analysis of variance for the single regression model for water dispersible colloids versus silt plus clay content.

Source	Sum of Squares	d.f.	Mean square	F ratio	p value
Model	37.39	2	18.69	16.51	***
Residual	5.66	5	1.13		
Total (corr.)	43.06	7			

R^2 = 86.9 percent; R^2 (adjusted for d.f.) = 81.6 percent; Standard Error of Estimate = 1.064; Mean absolute error = 0.755; Durbin-Watson statistic = 1.36 (P=0.01). (***) significant at <0.001.

Table 3.6: Polynomial regression analysis between water dispersible colloids (WDC) and the silt plus clay as an independent variable.

Parameter	Estimate	Standard error	T statistic	p Value
Constant	32181.500	7687.070	4.18	***
Silt + Clay	-689.500	164.950	-4.18	***
$(\text{Silt} + \text{Clay})^2$	3.693	0.884	4.17	***
Abbreviations: (***) significant at < 0.001.				

3.1.2. The effect of tillage system on selected soil chemical parameters

Values of soil chemical parameters in the Calloway silt and the Maury silt loam soils are shown in Table 3.7. Because both soils were well drained, very low exchangeable Na content (Exch. Na) was expected. The highest value corresponded to the Maury soil under CT and the lowest value in the Calloway soil, which shows no differences between CT and NT. However, these differences should not have consequences on soil stability because the absolute values and the proportion of Exch. Na on the cation exchange capacity (CEC) in both soils are negligible (Table 3.7).

3.1.2.1. Exchangeable K

The Maury silt loam soil with continuous corn had the highest Exch. K content in NT in 0 to 5 cm soil depth, significant at $p<0.05$ (Table 3.7). The Exch. K value under CT was lower than NT. However, the Calloway silt soil with the corn-soybean rotation showed no differences in Exch. K content between CT and NT, but these values were lower than Exch. K values in the Maury soil ($p<0.05$).

3.1.2.2. Exchangeable Ca and Mg

The Maury soil under CT had the highest exchangeable Ca (Exch. Ca) content, and the Calloway soil under CT had the lowest value (Table 3.7). Therefore, Exch. Ca under NT showed no differences between the Maury soil and the Calloway soil ($p<0.05$). In addition, exchangeable Mg (Exch. Mg) content differed neither with tillage nor with soils (Table 3.7).

3.1.2.3. Cation exchange capacity (CEC) and pH

The Maury soil showed no differences between the two tillage systems, but in the Calloway soil, CEC was higher under NT than under CT ($p<0.05$) (Table 3.7). This could be a consequence of the different TOC content (Table 3.1).

Table 3.7: Average values of selected soil chemical parameters (0-5 cm soil depth) from the Calloway silt soil and the Maury silt loam soil under No tillage (NT) and Conventional (intensive) tillage (CT).

Tillage	Na	K	Ca	Mg	CEC	pH	EC
Soil	--		cmol kg^{-1}			- -	- dS m^{-1}-
NT Maury	0.05b	0.96c	7.45b	0.29a	10.97c	6.60b	0.09a
CT Maury	0.08c	0.35b	8.26c	0.28a	10.56c	6.20a	0.10a
NT Calloway	0.03a	0.23a	7.45b	0.30a	9.46b	6.90c	0.11a
CT Calloway	0.03a	0.24a	4.19a	0.23a	6.79a	7.10c	0.12a

Abbreviations: Na =exch. Sodium; K = exch. Potassium; Ca= exch. Calcium; Mg= exch. magnesium; CEC= Cation exchange capacity; EC= electrical conductivity. Different letters in the same column means significant with $p<0.05$ according to the LSD test. n=4

In the Maury soil, pH was lower under CT than under NT (Table 3.1). However, the opposite situation was observed in the Calloway soil. Probably, soil management (type and amount of fertilizer) and crop rotation could be more responsible than tillage to cause significant changes in pH. This is because crop rotation could imply different root systems and different kinds of crop residue that are important inputs to modify soil micro-environments (Angers et al., 1995; Ball et al., 2005; D'Haene et al., 2008).

In order to analyze consequences of soil chemical parameters on the soil structure, statistical relationships between different cations and aggregate stability indexes are shown in Table 3.8. Alkaline-earth cations (Ca and Mg) were positively related with MWD and GMD ($p<0.05$). However, these cations had no relationships with WSA, which suggests that the water stability depended on other agents. Exchangeable K, Exch. Na and Fe $_{(ox)}$ were not significant related to MWD and GMD, which suggests that these cations were not relevant for soil aggregation.

3.1.3. The effect of tillage systems on selected characteristics of soil aggregates

Analysis of main effects and interactions on 8 mm aggregates from Maury and Calloway soil under both tillage systems (Table 3.9) were significant for aggregates volume. Significant interactions soil by tillage means that differences produced by tillage systems were higher in the Maury soil than in Calloway soil (Table 3.9).

Aggregate density and porosity differed in both sites, but tillage systems had no significance on these parameters (Table 3.9). No significance ($p<0.05$) was observed in the interactions. It would have been expected that tillage systems increased bulk density but few studies have analyzed aggregate density. Thus, it is possible that soil parameters like organic matter and clay content can play an important role in density and porosity of aggregates.

Like three-dimensional structures, soil aggregates have both, geometrical and morphological characteristics that could be affected by tillage systems. These aspects were explored by using several aggregate shape factors as defined in Section 2. The shape factor (SF) (Eq. 1) represents the relationship among the aggregate's dimensions (Figure 2.2), i.e., when all dimensions are equal, the value of SF should be 1.

Table 3.8: Pearson correlations among selected soil chemical parameters, geometric mean diameter and mean weight diameter of soil aggregates.

Source	Ca	Mg	K	Na	Fe
GMD	0.93	0.86	0.50	0.50	0.60
	(***)	(***)	NS	NS	NS
MWD	0.94	0.90	0.60	0.60	0.50
	(***)	(***)	NS	NS	NS

Abbreviations: GMD = Geometric mean diameter; MWD= Mean weight diameter; (***) significant at <0.001; NS= not significant (α= 0.05).

Table 3.9: Average values of selected soil parameters and p-values of two-factor analysis for 8 mm aggregate size in the Maury silt loam and the Calloway silt soil under conventional tillage (CT) and no tillage (NT).

Soil Treatment	SF	V (cm^3)	ρ_b ($g\ cm^{-3}$)	Φ ($cm^3\ cm^{-3}$)	Flat	El	Sphe	Circ	Rug
Maury CT	0.75	1.40	1.10	0.65	1.35	0.65	0.34	0.58	1.76
Maury NT	0.62	0.86	1.12	0.69	1.50	0.51	0.37	0.60	1.72
Calloway CT	0.70	1.03	1.12	0.74	1.23	0.61	0.43	0.64	1.61
Calloway NT	0.70	0.97	1.10	0.74	1.29	0.62	0.39	0.62	1.64
Main sources and interaction									
A. Soil	NS	*	*	*	*	NS	NS	NS	*
B. Tillage	**	***	NS	NS	*	**	NS	NS	NS
A x B	*	*	NS	NS	NS	**	NS	NS	*

Abbreviations: SF= shape factor; V= volume; ρ_b=aggregate density; Φ= porosity; Flat= flatness; El= elongation ratio; Sphe= sphericity; Circ= circularity; Rug= rugosity; n=30. NS= not significant (α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

Shape factor was not affected by soil, but depended on tillage. It can be observed in Table 3.9 that the highest value of SF was measured in the Maury soil under CT and the lowest value also was measured in Maury soil but under NT. The significance in interaction showed that tillage systems were responsible for differences in SF values in the Maury soil but not in Calloway soil.

Flatness was affected by both soil and tillage, but the interaction was not significant, which means that both sources of variation were independent. Flatness values were higher in the Maury soil than in the Calloway soil, and under NT, values tended to be higher than under CT (Table 3.9). Tillage systems were responsible for the planar shape of these aggregates. No significance was observed for sphericity and circularity. Conversely, rugosity was related only to soil characteristics, as was indicated by the significance of main effects and interaction. This significance identified soil characteristics were largely responsible for aggregates rugosity and despite the differences due to tillage systems, values for the Maury soil were higher than for the Calloway soil.

The two-factor analysis performed on aggregates of 4.75 mm from Maury and Calloway soil under CT and NT are shown in Table 3.10. Aggregate volume, density and porosity were affected for soil and tillage systems and the interaction was significant for volume and bulk density ($p<0.05$). The aggregate volume was higher under CT than under NT in the Maury soil but the opposite occurred in the Calloway soil (Table 3.10). In addition, aggregate density was always higher under NT than under CT in both soils, especially in the Maury soil.

The shape factor and the elongation ratio were modified only by tillage systems. Interaction resulted not significant. Both, SF and El values were higher under CT than under NT.

Flatness was not the result of the factors evaluated here. No significance in soil, tillage or interaction was coherent and supported this conclusion. Flatness index showed that soil aggregates tend to be more planar than spherical, because values were higher than 1 (Table 3.10). At this aggregate level the common assumption about NT tending to

Table 3.10: Average values of soil parameters and p-values of two-factor analysis for 4.75 mm aggregate size in the Maury silt loam and the Calloway silt soil under conventional tillage (CT) and no tillage (NT).

Soil Treatment	SF	V (cm^3)	ρ_b ($g\ cm^{-3}$)	Φ ($cm^3\ cm^{-3}$)	Flat	El	Sphe	Circ	Rug
Maury CT	0.79	0.34	0.99	0.62	1.38	0.68	0.85	0.92	1.10
Maury NT	0.65	0.17	1.40	0.46	1.35	0.56	1.25	1.10	0.91
Calloway CT	0.70	0.18	0.97	0.72	1.35	0.65	0.43	0.64	1.60
Calloway NT	0.64	0.27	1.09	0.74	1.30	0.58	0.35	0.58	1.78
Main sources and interaction									
A. Soil	NS	**	***	***	NS	NS	***	***	***
B. Tillage	***	**	*	***	NS	**	***	*	NS
A x B	NS	***	***	NS	NS	NS	***	***	**

Abbreviations: SF= shape factor; V= volume; ρ_b=aggregate density; Φ= porosity; Flat= flatness; El= elongation ratio; Sphe= sphericity; Circ= circularity; Rug= rugosity. n=30. NS= not significant (α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

produce planar aggregates was not supported by the data.

The geometric shape of aggregates, represented by sphericity and circularity, was a consequence of the interaction of soil by tillage (Table 3.10). In the Maury soil values of both parameters were higher than in the Calloway soil and under NT were higher than under CT. The opposite tillage trend was observed in the Calloway soil.

Interaction soil by tillage was significant for rugosity. In the Calloway soil rugosity was higher under NT than under CT and in the Maury soil was the opposite.

In aggregates of 2.78 mm (Table 3.11), soil was more significant than tillage systems on these soil parameters. Soil significantly influenced all the parameters except flatness and elongation ratio, but tillage systems only affected rugosity. Aggregate volume was lower in the Maury soil than in the Calloway soil and the opposite was observed with aggregate density. As occurred with aggregates of 4.75 mm, flatness was not affected for the factors considered in this study. Elongation ratio, sphericity and circularity were higher in the Maury soil than in the Calloway soil.

Rugosity was the only parameter affected by the interaction soil and tillage ($p<0.05$). In the Calloway soil, rugosity values were higher than in the Maury soil and were higher under CT than under NT. No difference due to tillage was observed in the Maury soil.

3.1.4. Effect of tillage systems on selected soil chemical and biological parameters in different aggregate size

Two-factor analysis performed on aggregates of 8 mm for Maury and Calloway soils under CT and NT are shown in Table 3.12. All main and interactions effects were significant, which highlighted the importance of considering both soil and tillage when evaluating soil chemical and biological parameters. Exchangeable Na is not important in well drained soils like the Maury or the Calloway. However, notice that the highest value was measured under CT in the Maury soil and the lowest under CT in the Calloway soil. No differences in Exch. Na were found under NT ($p<0.05$).

Table 3.11: Average values of soil parameters and p-values of a two-factor analysis for 2.78 mm aggregate size in the Maury silt loam and the Calloway silt soil under conventional tillage (CT) and no tillage (NT).

Soil Treatment	SF	V (cm^3)	ρ_b ($g\ cm^{-3}$)	Φ ($cm^3\ cm^{-3}$)	Flat	El	Sphe	Circ	Rug
Maury CT	0.76	0.06	1.32	0.49	1.22	0.69	4.64	2.13	0.48
Maury NT	0.71	0.06	1.30	0.51	1.24	0.65	5.20	2.22	0.47
Calloway CT	0.64	0.09	1.10	0.75	1.38	0.61	0.21	0.46	2.23
Calloway NT	0.66	0.08	1.11	0.75	1.34	0.58	0.29	0.53	1.94
Main sources and interaction									
A. Soil	**	***	***	***	NS	NS	***	***	***
B. Tillage	NS	NS	NS	NS	NS	NS	NS	NS	**
A x B	NS	NS	NS	NS	NS	NS	NS	NS	**

Abbreviations: SF= shape factor; V= volume; ρ_b=aggregate density; Φ= porosity; Flat= flatness; El= elongation ratio; Sphe= sphericity; Circ= circularity; Rug= rugosity. n=30. NS= not significant (α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

Table 3.12: Average values of different soil chemical and biological parameters in aggregates of 8 mm size in the Maury and in the Calloway silt soil under conventional tillage (CT) and no tillage (NT) and probability values from two-factor analysis with interactions.

Soil	Tillage system	Na (cmol kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	$Fe_{(ox)}$ (mg Kg^{-1})	TOC (g kg^{-1})	POM -C (g kg^{-1})
Maury	NT	0.03	0.30	5.59	0.10	40.10	19.60	15.15
	CT	0.05	0.30	6.23	0.21	39.90	10.00	5.37
Calloway	NT	0.03	0.33	4.11	0.63	19.06	11.45	2.75
	CT	0.02	0.20	7.21	0.10	13.13	10.11	2.72
		Main effects and interaction						
A. Soil		***	***	***	***	***	***	***
B. Tillage		*	***	***	***	**	**	***
A x B		***	**	***	***	**	***	**

Abbreviations: Na= sodium; K = potassium; Ca= calcium; Mg= magnesium; $Fe_{(ox)}$= oxalate extractable iron; TOC= total organic carbon; POM-C= Particulate organic matter. NS= no significant(α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

Exchangeable K was higher under NT than under CT in the Calloway soil. No difference was observed in the Maury soil between both tillage systems. Exchangeable Ca resulted higher under CT than under NT in both soils. Although both are alkaline-earths elements, Exch. Mg showed a different trend than Exch. Ca. Exch. Mg was higher under NT than under CT in the Calloway soil and the opposite trend was observed in the Maury soil.

Oxalate extractable Fe (Fe_{ox}) content showed no differences between the two tillage treatments in the Maury soil and was higher in this soil than in the Calloway soil. Under NT, it was higher than under CT in the Calloway soil. Total organic carbon (TOC) in both soils was higher under NT than under CT. No differences were observed in both soils under CT ($p<0.05$). In the case of particulate organic matter (POM-C) the highest value was observed under NT in the Maury soil, and in the Calloway soil, tillage systems showed no differences.

In aggregates of 4.75 mm (Table 3.13), soil was not significant for Exch. Na, but tillage and interaction resulted in significant effects ($p<0.05$). As was mentioned previously, Exch. Na content was too low to cause any consequences on the behavior of these soils. In case of Exch. K content, this cation was affected by soil but not by tillage and the interactions resulted significant. The differences in Exch. K content produced by tillage in the Calloway soil were higher than in the Maury soil.

In the same sense, interaction soil by tillage resulted significant for Exch. Ca content and the differences produced by tillage were higher in the Calloway soil than in the Maury soil. Exchangeable Mg, $Fe_{(ox)}$ content, TOC and POM-C also were affected by the interaction soil and tillage (Table 3.13). Differences in Exchangeable Mg and $Fe_{(ox)}$ content produced by tillage were higher in the Maury soil than in the Calloway soil. On the contrary, TOC and POM-C differences produced by tillage were higher in the Maury than in the Calloway soil.

Two-factor analysis in the case of aggregates of 2.78 mm is shown in Table 3.14. Exch. Na was affected by soil and tillage but the interaction was insignificant ($p<0.05$), which means that they were independent.

Table 3.13: Average values of different soil chemical and biological parameters in aggregates of 4.75 mm size in the Maury and in the Calloway silt soil under conventional tillage (CT) and no tillage (NT) and probability values from two-factor analysis with interactions.

Soil	Tillage system	Na (cmol kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	$Fe_{(ox)}$ (mg Kg^{-1})	TOC (g kg^{-1})	POM-C (g kg^{-1})
Maury	NT	0.04	0.30	6.15	1.08	18.02	19.55	7.46
	CT	0.03	0.27	5.49	0.74	19.05	9.45	2.52
Calloway	NT	0.02	0.17	7.48	0.35	7.69	13.10	5.10
	CT	0.04	0.23	4.03	0.13	5.30	8.80	1.84
Main effects and interaction								
A. Soil		NS	***	NS	***	***	*	**
B. Tillage		**	NS	***	***	*	**	***
A x B		***	***	***	*	**	*	**

Abbreviations: Na= sodium; K = potassium; Ca= calcium; Mg= magnesium; $Fe_{(ox)}$= Oxalate extractable iron; TOC= total organic carbon; POM-C= Particulate organic matter. NS= not significant (α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

Table 3.14: Average values of different soil chemical and biological parameters in aggregates of 2.78 mm size in the Maury and in the Calloway silt soil under conventional tillage (CT) and no tillage (NT) and probability values from two-factor analysis with interactions.

Aggregate size (mm)	Soil	Tillage system	Na (cmol kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	Fe$_{(ox)}$ (mg Kg^{-1})	TOC (g kg^{-1})	POM -C (g kg^{-1})
Maury		NT	0.03	0.33	6.42	1.19	16.05	21.20	17.75
		CT	0.02	0.23	5.29	0.65	14.45	9.50	1.10
Calloway		NT	0.02	0.20	8.17	0.28	13.11	14.10	8.67
		CT	0.01	0.17	3.84	0.09	10.26	8.95	0.99
Main effects and interaction									
A. Soil			***	***	*	***	**	***	***
B. Tillage			*	***	***	*	*	***	***
A x B			NS	**	***	***	NS	**	***

Abbreviations: Na= sodium; K = potassium; Ca= calcium; Mg= magnesium; Fe$_{(ox)}$= Oxalate extractable iron; TOC= total organic carbon; POM-C= Particulate organic matter. NS= not significant (α= 0.05); (*) significant at <0.05; (**) significant at < 0.01: (***) significant at <0.001.

Exch. K, Ca and Mg were affected by soil, tillage and their interaction. Tillage produced higher differences in Exch. K and Exch. Mg in the Maury soil than in the Calloway soil. However, the opposite was observed with differences in Exch. Ca produced by tillage and were lower in the Maury soil than in the Calloway soil.

In case of $Fe_{(ox)}$ content, soil and tillage were significant, but not their interaction (Table 3.14). TOC and POM-C values were affected by soil and tillage and the interaction was significant. In the Maury soil, tillage differences in TOC and POM-C observed under NT were higher than in the Calloway soil.

3.2 Effect of high and low kinetic energy wetting on particle release at soil aggregates and field scale

3.2.1. Effect of high and low kinetic energy wetting on wetting rate, water content and particle release in soil aggregates

Water uptake measured in the lab in aggregates under CT and NT from the Maury soil is shown in Figure 3.3. Notice that the final time in this experiment represents the moment of aggregate breakdown. In Figure 3.3, time to aggregate rupture decreased when the aggregate size decreased. The same situation was observed with the water uptake. Values observed under CT were higher than values under NT ($p<0.05$), but only until 8 minutes in aggregates of 8 mm (Figure 3.3 a). In aggregates of 4.75 and 2.78 mm, water uptake was higher under CT than under NT only at 2 minutes (Figure 3.3 b and c). The same comparisons between tillage realized in the Calloway soil are shown in Figure 3.4. As occurred with the Maury soil, similar behavior was observed between time to rupture and the magnitude of water uptake. Both parameters decreased when the aggregate size decreased. However, under NT, water uptake values in aggregates of 8 mm were higher than under CT, as opposed to what was observed in the Maury soil, and only until 7 minutes. No significant differences were observed in aggregates of 4.75 and 2.78 mm when both tillage systems were compared.

Three-factor analysis for wetting rate values calculated according to Rasiah and Kay (Rasiah and Kay, 1995) with (k_{di}) and without drop impact (k) is shown in Table 3.15. Aggregates of 2.78 and 4.75 mm exhibited a similar response to the main effects, and both showed a soil by tillage by wetting rate interaction. The k_{di} values were higher than the k values despite soil differences (Table 3.15). Tillage effect on k values was not clear, but k_{di} was higher under CT than under NT in both soils.

The second order interaction soil by tillage by energy was significant for both, aggregates of 2.78 mm and aggregates of 4.75 mm. However, in aggregates of 2.78 mm was higher in the Calloway soil than in the Maury soil. In aggregates of 4.75 mm, these

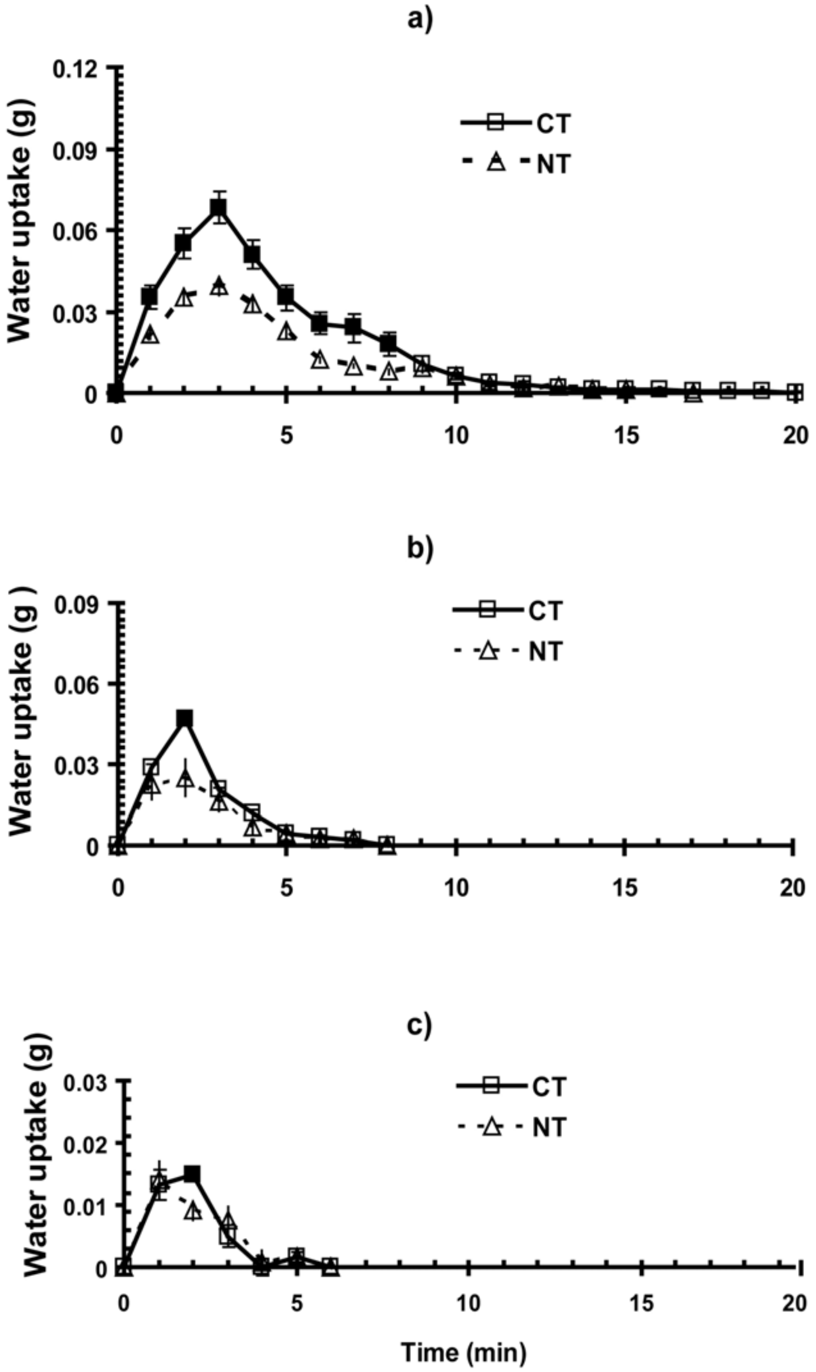


Figure 3.3: Water uptake in a) 8 mm, b) 4.75 mm and c) 2.78 mm aggregates from the Maury soil under conventional (CT) and no tillage (NT). Filled symbols represent significant differences at $p < 0.05$.

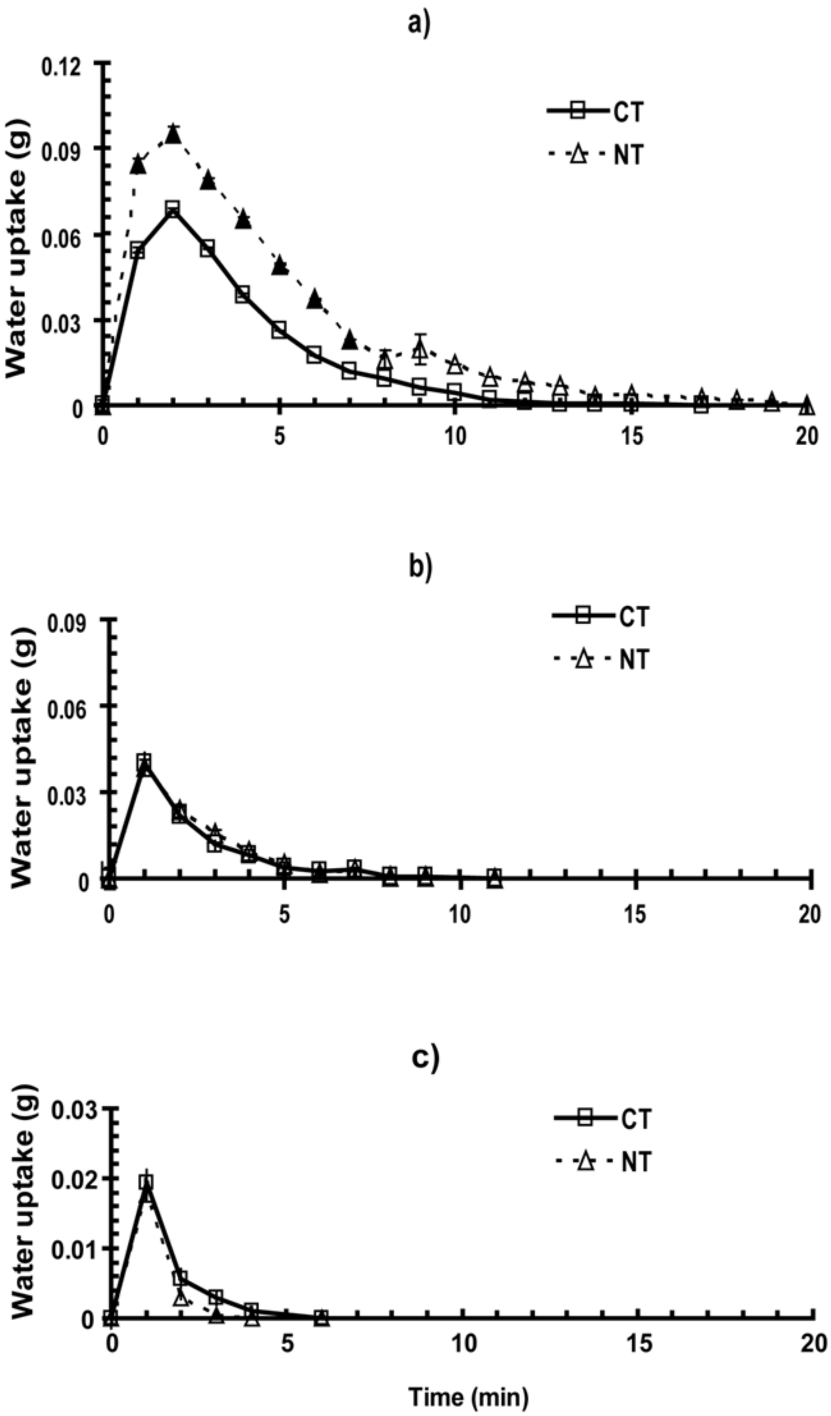


Figure 3.4: Water uptake in a) 8 mm, b) 4.75 mm and c) 2.78 mm from the Calloway soil under conventional (CT) and no tillage (NT). Filled symbols represent significant differences at $p<0.05$.

Table 3.15: Three-factor analysis and wetting rate values (g min^{-1}) measured without drop impact (k) and with drop impact (k_{di}) in different aggregate size classes from Maury and Calloway soil under conventional (CT) and no tillage (NT).

Soil	Tillage system	Aggregate size					
		2.78 mm		4.75 mm		8 mm	
		k	k_{di}	k	k_{di}	k	k_{di}
Calloway	CT	0.56	7.8	0.49	4.8	0.41	6.0
	NT	0.60	6.0	0.48	4.8	0.32	10.2
Maury	CT	0.52	7.2	0.47	6.0	0.36	5.4
	NT	0.52	6.6	0.45	8.4	0.27	9.0
Main source and interaction							
A. Soil		NS		NS		*	
B. Tillage		***		***		**	
C. Energy		***		***		***	
AB		**		*		NS	
AC		NS		NS		*	
BC		***		***		***	
ABC		***		*		NS	

Abbreviations: NS = not significant (α= 0.05); (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

differences in wetting rate were higher in the Maury soil than in the Calloway soil.

Soil characteristics, tillage and energy influenced wetting rate in aggregates of 8 mm. Significance in the soil by energy interaction was present because the differences in wetting rate was higher in the Calloway soil than in the Maury soil. Interaction tillage by energy showed that NT caused more differences in wetting rate than CT.

Gravimetric water content at rupture for aggregates of 2.78 mm with (WC_{di}) and without (WC) drop impact depended only on the soil characteristics (Table 3.16). The WC and WC_{di} values for the Calloway soil were lower than in the Maury soil (Table 3.16).

However, in aggregates of 4.75 mm, the soil by energy wetting interaction was significant, although tillage and energy were not significant as main effects. The Calloway soil had lower values of WC and WC_{di} than the Maury soil (Table 3.16). The interaction soil by energy suggested that differences in water content with and without impact before the rupture were higher in the Calloway soil than in the Maury soil.

Significant soil by tillage and soil by wetting energy interactions of the WC and WC_{di} values for 8 mm aggregate size were observed (Table 3.16). In the Maury soil WC values were higher under CT than under NT, but no such difference was observed with WC_{di}. In the Calloway soil, no difference was observed in WC or WC_{di}.

Volumetric water content with (VWC_{di}) and without drop impact (VWC) were also analyzed and results are displayed in Table 3.17. No significance was observed for aggregates of 2.78 mm in second order interaction (soil by tillage by energy) but soil by tillage interaction was significant. In the Calloway soil under CT, volumetric water content was higher than in the Maury soil.

Interaction soil by tillage was significant in aggregates of 4.75 mm. Differences caused by tillage was higher in the Maury soil under NT. Energy and soil as main effects were significant, VWC_{di} was higher than VWC. The Maury soil had more VWC_{di} than the Calloway soil.

Table 3.16: Three-factor analysis and gravimetric water content values before aggregate rupture without drop impact (WC) and with drop impact (WC_{di}) in different aggregate size classes from Maury and Calloway soil under conventional (CT) and no tillage (NT).

Soil	Tillage system	Aggregate size					
		2.78 mm		4.75 mm		8 mm	
		WC	WC_{di}	WC	WC_{di}	WC	WC_{di}
Calloway	CT	0.32	0.34	0.33	0.26	0.31	0.12
	NT	0.32	0.27	0.32	0.30	0.32	0.10
Maury	CT	0.50	0.45	0.38	0.43	0.33	0.19
	NT	0.44	0.42	0.45	0.44	0.24	0.18
Mains source and interaction							
A. Soil		**		***		NS	
B. Tillage		NS		NS		*	
C. Energy		NS		NS		***	
AB		NS		NS		*	
AC		NS		*		***	
BC		NS		NS		NS	
ABC		NS		NS		NS	

Abbreviations: NS = not significant (α= 0.05); (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

Table 3.17: Three-factor analysis and volumetric water content values before aggregate rupture without drop impact (WC) and with drop impact (WC_{di}) in different aggregate size classes from Maury and Calloway soil under conventional (CT) and no tillage (NT).

Soil	Tillage system	Aggregate size					
		2.78 mm		4.75 mm		8 mm	
		WC	WC_{di}	WC	WC_{di}	WC	WC_{di}
Calloway	CT	0.50	0.50	0.38	0.40	0.48	0.22
	NT	0.42	0.44	0.37	0.51	0.38	0.24
Maury	CT	0.47	0.51	0.39	0.44	0.40	0.20
	NT	0.46	0.50	0.47	0.50	0.33	0.22
Main source and interaction							
A. Soil		NS		**		***	
B. Tillage		NS		NS		NS	
C. Energy		NS		***		*	
AB		**		**		NS	
AC		NS		NS		NS	
BC		NS		NS		NS	
ABC		NS		NS		*	

Abbreviations: NS = not significant (α= 0.05); (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

Second order interaction (soil by tillage by energy) in aggregates of 8 mm was significant. The differences in volumetric water content with and without drop impact were higher in the Calloway soil under CT.

The k and k_{di} data signal that the wetting rate with drop impact was the highest, but could not produce the highest aggregate water content. This result suggested that wetting rate was more important than water content in producing aggregate rupture in these soils. The fact that the faster the wetting rate, the lower the water content necessary to initiate the rupture implies that a mechanism related with internal aggregate pressure was involved, i.e., slaking. Conversely, with slow wetting the highest water content prior to aggregate rupture was observed, which suggested that the mechanism involved was a physicochemical dispersion due to osmotic stress on wetting with low-electrolyte water.

Pearson correlations were used to explore the relationship among aggregate properties, and both wetting rate and water content (Table 3.18). Aggregate volume strongly and negatively influenced k values, and these were not affected by other aggregate soil parameters, neither TOC nor clay content. Note that this was a strong inverse relationship. Parameters that might normally be related to the wetting rate, k, such as aggregate density or porosity, exhibit no such relationship in this study. This could be a consequence of high pore heterogeneity or lack of connectivity in the pore system within these large aggregates.

As expected, WC was positively related with k values. In addition, several aggregate parameters were related to WC. Of special importance were the direct relationship of k with aggregate density and the inverse relationship with volume and total porosity, because these support the hypothesis regarding a lack of connectivity in the aggregate pore system. It is not clear why flatness has an inverse relationship with water content, but if the pore system was aligned along one axis, for example parallel to the tension table, this could reduce water uptake. Similarly, pore geometry could be responsible for the inverse relationship between WC and rugosity or the positive relationship between WC and other parameters.

Rugosity represents the aggregate perimeter as compared to the perimeter of a circle, which in all cases showed that these aggregates tend to be more like polyhedrons

Table 3.18: Pearson correlation of different aggregate soil parameters, soil properties, water content and wetting rate measured with different procedures.

Source	k	WC	k_{di}	WC_{di}
TOC	NS	NS	0.34*	NS
POM-C	NS	NS	NS	NS
TOC rsq	NS	NS	0.33*	NS
POM-C rsq	-0.34*	NS	NS	NS
WSA	NS	0.33*	0.59***	0.45**
CLAY	NS	0.38**	0.38**	NS
SF	NS	0.38**	NS	NS
VOL	-0.81****	-0.57***	-0.52**	- 0.83****
Density	NS	0.71****	0.68****	0.53***
Porosity	NS	-0.70****	-0.68****	- 0.54***
Flatness	NS	-0.60****	NS	NS
Elongation	NS	0.56****	NS	NS
Sphericity	NS	0.78****	0.66****	0.62****
Circularity	NS	0.80****	0.66****	0.62****
Rugosity	NS	-0.72****	-0.51**	- 0.52***
WC	0.52***			
k		0.52***		
WC_{di}			0.51***	
k_{di}				0.51***

Abbreviations: k= wetting rate; WC= water content; k_{di}= wetting rate with kinetic energy; WC_{di}= Water content with kinetic energy; TOC= total organic carbon; TOC sqr= square root of TOC; POM-C= particulate organic matter; POM-C rsq= square root of POM-C; WSA= water stable aggregates; SF= shape factor; VOL= volume; n=30; NS= not significant (α= 0.05); *= significant at p<0.05; **= significant at p <0.01; ***=significant at p<0.001; ****= significant at p<0.0001.

than spherical. An intricate pattern of porous geometry could be expected in a complex aggregate shape, which determines that some regions within the aggregate became saturated at the same time when others did not, creating inner aggregate failure zones. In such a scenario, aggregates begin the rupture before becoming fully saturated with water. However, this assumption does not explain the direct relationship between elongation and WC, because this positive relationship implies that y-axis- and x-axis-related pore systems are active at the same time. The ambiguity resulting from these different relationships indicates that detailed observations of the inner pore geometry are needed to precisely identify the reason behind the observed behavior.

Further, it was not clear why TOC was not related to WC. One reason could be that a different kind of organic carbon was involved in this response. To reduce the variability in data, the TOC square root (TOC SqR) was tested, but caused no differences on WC or k. However, the POM-C square root (POM-C SqR) showed a negative relationship with k. Conversely, clay content was positively related with WC as was expected.

Pearson correlation analysis between k_{di} and other aggregate parameters (Table 3.18), found significant relationships with TOC, TOC SqR, WSA and clay content. Again, aggregate density, total porosity and volume exhibited similar behavior as occurred with k values, thus suggesting a coherent relationship to the connectivity of aggregate pore systems. In addition, the WSA was always related with WC, k_{di} and WC_{di}.

When the water content with drop impact (WC_{di}) was examined, an unexpected behavior was observed, i.e., no relationships were observed among WC_{di}, POM-C, TOC and clay content. One possible explanation could be that the variability was too high to define a trend due to the nature of the drop impact procedure, which could force the water to enter the aggregate. Other aggregate parameters exhibited similar behavior with WC_{di} as observed with WC, and are explained as was done above.

A matrix plot among clay content, TOC, TOC SqR, POM-C, POM-C SqR, k, k_{di}, WC and WC_{di} in Figure (3.5) shows that in fact, these relationships are strongly non-linear. Notice that the relationships with wetting rate and water content remained non-

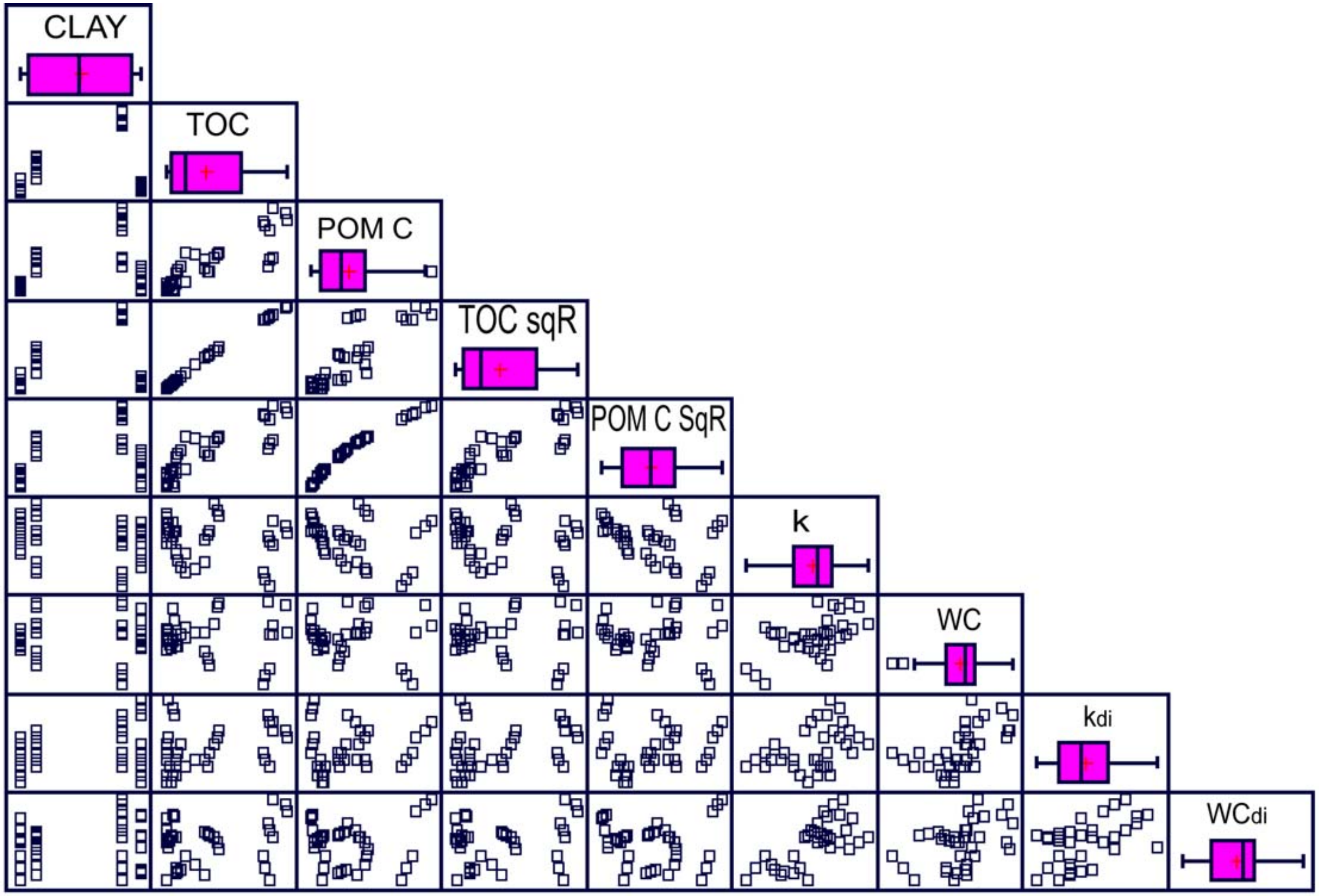


Figure 3.5: Matrix plot among clay content (CLAY), total organic carbon (TOC), TOC square root (TOC sqR), particulate organic matter (POM-C), POM-C square root (POM-C SqR), wetting rate with (kdi) and without drop impact (k), gravimetric water content with (WCdi) and without drop impact (WC) in both, the Calloway and the Maury soil under CT and NT.

linear even with the square roots of TOC and POM-C.

An examination of these relationships at aggregate scale was performed in Figure 3.6. Note that in the Maury soil under CT an overlapping effect of k values appeared with aggregates of 2.78 and 4.75 mm at TOC concentration of 9.6 g kg^{-1}. These aggregates had a clay content of 26.9 g 100 g^{-1}. In addition, k values decreased at low TOC values (Figure 3.6) and increased beyond a TOC value of 10 g kg^{-1}. In the Maury soil, these aggregates belong to NT system, with a clay content of 23.6 g 100 g^{-1}.

In the Calloway soil, a similar behavior was observed in the same aggregate size ranges (from 2.78 to 4.75 mm) under CT but with a clay content of 11.2 g 100 g^{-1} and TOC concentration of 9 g kg^{-1} (Figure 3.6). Again, under NT, k values increased with TOC content. The regression model used to fit these data showed a similar slope under NT in both, the Calloway and the Maury soil.

Interestingly, as occurred with TOC in the Maury soil under CT, k decreased with POM-C. However, under NT, k values increased with POM-C, except with aggregates of 4.75 mm (Figure 3.6). The behavior of this aggregate size is not clear, and no linear model but a polynomial model was needed to fit the data.

In the Calloway soil, an overlapping effect occurred between aggregates of 8 mm from CT and NT, which clay content of 11.2 and 13.2 g 100 g^{-1}, respectively. At very low POM-C content, k values showed a negative relationship that became positive when POM-C was higher than 5 g kg^{-1}, approximately (Figure 3.6).

To further analyze relationships among wetting rate and these aggregation factors, the change in k and k_{di} (g min^{-1}) value per unit of TOC (g kg^{-1}), POM-C (g kg^{-1}) and clay content (g 100 g^{-1}) from each aggregate size were used to build a multiple range test of differences at the aggregate scale. Because these soil parameters could modify the relationship between soils and wetting rate, these ratios might indicate the level of responsibility associated with different components, especially if different kinds of organic carbon were involved in wetting rate response for individual aggregate sizes. In the same sense, overlapping effects caused by the interaction clay-organic carbon could be identified.

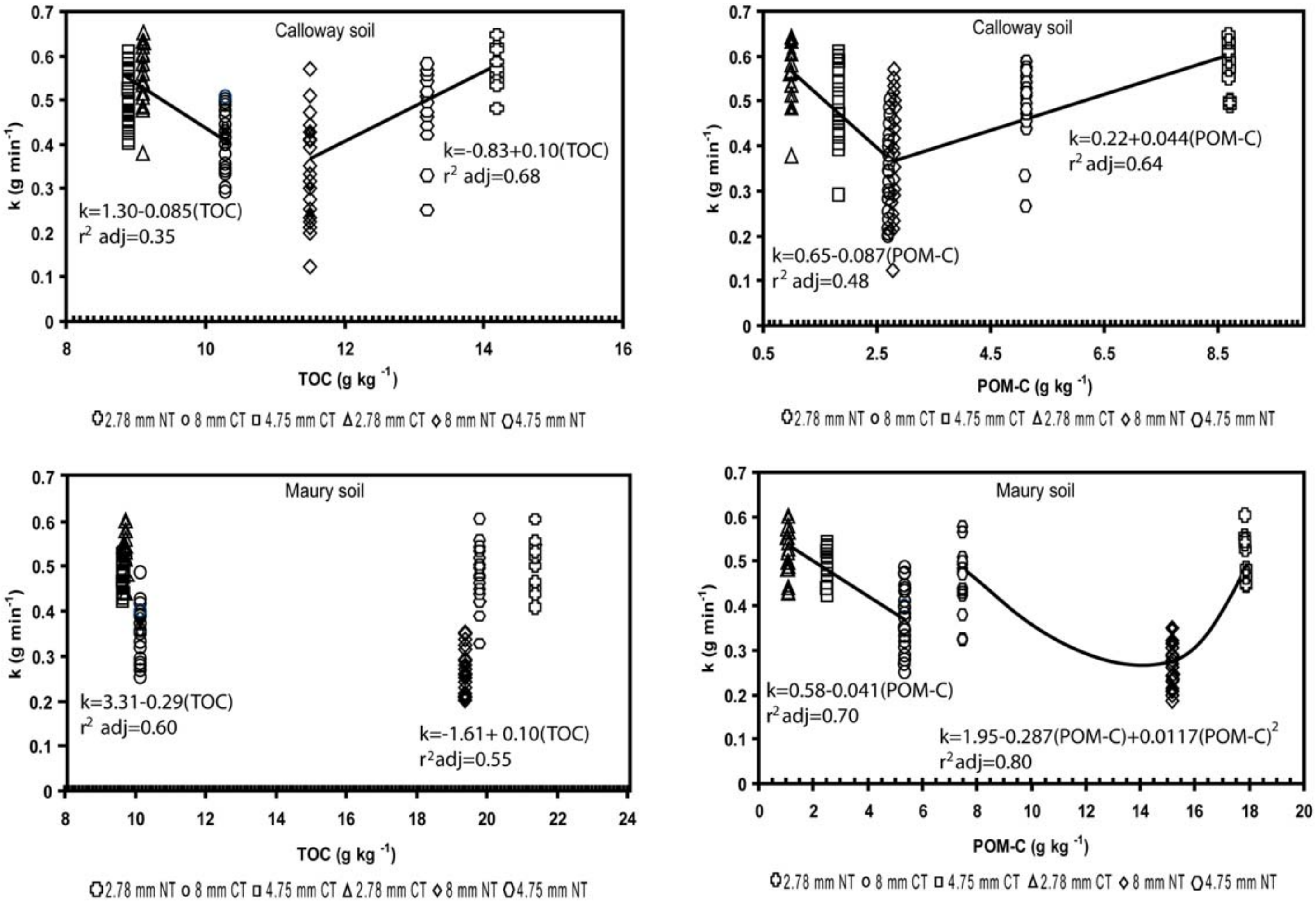


Figure 3.6: Relationships among wetting rate (k), total organic carbon (TOC) and particulate organic carbon (POM-C) in different aggregate size from the Calloway and the Maury soils under conventional (CT) and no tillage (NT).

Table 3.19: Multiple-range-test for the ratio among wetting rate, total organic carbon, particulate organic matter and clay content in the Calloway and the Maury soils under conventional and no tillage.

Soil	Tillage system	Aggregate Size	k/TOC	k/POMC	k_{di}/TOC	k_{di}/POMC	k/Clay	k_{di}/Clay
		Mm	--	g min^{-1}/g kg^{-1}		--	-g min^{-1}/g $100g^{-1}$ -	
Maury	CT	2.78	0.05e	0.51f	0.92e	8.80f	0.02b	0.33a
		4.75	0.04d	0.42e	0.85d	7.32e	0.01a	0.31a
		8	0.03c	0.19d	0.71c	3.78d	0.01a	0.27a
	NT	2.78	0.02b	0.20d	0.33a	2.65c	0.02b	0.28a
		4.75	0.02b	0.16d	0.40b	2.90c	0.01a	0.33a
		8	0.01a	0.05b	0.36a	1.28c	0.01a	0.29a
Calloway	CT	2.78	0.06f	0.06b	0.70c	0.72b	0.03d	0.57c
		4.75	0.05e	0.02a	0.64c	0.32a	0.04c	0.51c
		8	0.04d	0.08c	0.56b	1.07b	0.05c	0.50b
	NT	2.78	0.04d	0.08c	0.39a	0.74b	0.02c	0.42b
		4.75	0.03c	0.05b	0.49b	0.74b	0.03c	0.50b
		8	0.02b	0.02a	0.50b	0.39a	0.04b	0.45b

Abbreviations: k = wetting rate ; k_{di}=wetting rate with drop impact; TOC= total organic content; POM-C= particulate organic matter. CT= conventional tillage; NT= No tillage. LSD test with α=0.05.

It can be observed in Table 3.19 that the ratio k/TOC decreased when the aggregate size increased, and this decrease was more pronounced under CT than under NT. This trend became clear in both soils, thus suggesting a strong relationship with organic carbon. To identify if different organic carbon fractions were responsible for this behavior, the existence of coherence between TOC and particulate organic matter (POM-C) response should be analyzed.

The effect of POM-C on k values can be observed in Table 3.19. As observed with TOC, k/POM-C ratio under CT tended to decrease when aggregate size increased. Notice that because the POM-C is only a fraction of TOC, the ratio k/POM-C was higher than the ratio k/TOC. By comparing the ratio responses in Table 3.19, it can be realized that different kinds of OC are involved in k behavior, and in the Calloway soil under NT, the k/POM-C ratio was closely related with k/TOC behavior. However, under CT in the Calloway soil, ratio k/POM-C tended to increase with aggregate size, as opposed to the ratio k/TOC. In the Maury soil under NT no trend was observed in aggregates of 2.78 and 4.75 mm but decrease in aggregates of 8 mm, thus suggesting that different kinds of OC were involved in both soils.

When the k_{di}/TOC ratio was evaluated (Table 3.19) a similar trend appeared as was mentioned before under CT, and the ratio decreased when aggregate size increased. However, an opposite behavior appeared under NT, and despite the soil type, the ratio tended to increase whith aggregate size increases. This was particularly remarkable in aggregates from the Calloway soil under NT. The ratio k_{di}/POM-C showed that particulate organic matter was important under CT in the Calloway silt soil, but was not important under NT, because there, the ratio was not changed with aggregate size (Table 3.19).

The clay content effect on k and k_{di} values behavior was also evaluated in Table 3.19. Clay content in the Maury soil under both tillage systems had no influence on the k and k_{di} values, but in the Calloway soil under CT and under NT, k/Clay ratio increased when the aggregate size increased. The opposite behavior was observed with k_{di}/Clay ratio in the Calloway soil under CT, but no relationships were found between aggregate size and k_{di}/Clay ratio under NT. These results could explain why no relationships were found in TOC and k values, because the clay content affected k values in opposite direction than TOC. Also, it is noticeable that the Maury soil had more clay than the Calloway soil (Table 3.1) but no relationship was found, thus suggesting that low clay content has a role in k value response.

3.2.2. Effect of low and high energy wetting at the aggregate scale

To determine consequences on particle release at the aggregate scale when two different energies were applied, an experiment was performed with aggregates of 8, 4.75 and 2.78 mm size with and without shaking in water during one hour. Results are shown in Table 3.19 in a three-factor analysis with interactions.

Soil type was extremely important for particle release with and without shaking. Soil significantly impacted release of different particle sizes (Groups a, b and c) but also the total amount (T) of particle release (Table 3.20). Tillage was also significant in almost all cases.

It is interesting to observe that energy, whose difference was produced with and without shaking the aggregates in water, significantly affected particles of all sizes released from aggregates of 8 mm. Aggregates of 8 mm generally released more total particles without shaking than with shaking.

However, this behavior was not observed for all aggregate size classes. When aggregates of 4.75 mm were shaken in water, differences were not found either in the total amount or in particles of Group a (greater than 0.105 mm). Also, differences were not observed in the quantity of particles greater than 0.105 mm released when aggregates of 2.78 mm were shaken in water. This behavior suggests differences in aggregate stability. Notice that the total amount of particles released and particles in Group c (smaller than 0.0053 mm, or silt-clay sized particles) tended to be higher in the Calloway soil than in the Maury soil. The interaction soil by energy means that the difference in silt-clay sized particles released was higher in the Calloway than in the Maury soil, caused when exposed to a high energy wetting.

The interactions soil by tillage was not significant for the release of particles higher than 0.105 mm in aggregates of 8 and 2.78 mm and for particles in Group b in aggregates of 4.75 mm. When we observe the soil by energy interaction, significance

Table 3.20: Three-factor analysis of particle release (g) with (Sh) and without shaking (NSh) in water from different aggregate size from Maury and Calloway soil under conventional (CT) and no tillage (NT).

Soil	Tillage system/ Energy	Aggregate size											
		2.78 mm				4.75 mm				8 mm			
		a	b	c	T	a	b	c	T	a	b	c	T
Calloway	CT Sh	6.7	2.8	10.5	20.0	13.0	2.2	7.2	22.3	8.8	1.7	4.2	14.7
	NT Sh	3.5	0.5	4.2	8.2	14.0	3.0	9.9	26.9	12.1	3.6	8.9	24.7
	CT NSh	6.3	1.1	4.6	12.0	11.1	5.4	6.0	22.5	19.4	5.3	3.5	28.2
	NT NSh	3.4	0.1	1.3	4.8	14.6	3.4	6.8	24.9	9.4	5.3	5.2	19.9
Maury	CT Sh	3.4	0.4	3.6	7.4	9.3	0.9	4.6	14.9	8.0	0.6	4.4	12.9
	NT Sh	0.1	0.0	0.1	0.3	0.8	1.0	4.6	6.4	1.3	1.1	1.2	3.6
	CT NSh	3.8	1.3	0.6	5.7	6.9	3.1	2.3	12.3	7.1	3.6	3.5	14.7
	NT NSh	0.2	0.0	0.1	0.2	4.7	0.6	1.2	6.4	0.8	2.1	1.5	4.4
Main source and interaction													
A. Soil		***	***	***	***	***	***	***	***	***	***	***	***
B. Tillage		***	***	***	***	*	*	**	**	***	NS	**	**
C. Energy		NS	**	***	***	NS	**	***	NS	**	***	**	***
AB		NS	***	***	*	***	NS	***	***	NS	**	**	*
AC		NS	***	***	**	NS	NS	NS	NS	NS	NS	**	NS
BC		NS	NS	***	*	**	**	***	NS	**	***	NS	**
ABC		NS	***	NS	NS	NS	NS	NS	NS	***	NS	***	***

Abbreviations: a= particles > 0.105 mm; b= mean particle size 0.079 mm; c= smaller than 0.053 mm; T= total; NS = not significant ($p < 0.05$); (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

occurred only with the release of particles smaller than 0.053 mm from aggregates of 8 mm and in the release of particles from aggregates of 2.78 mm (total amount, Groups b and c). This implies that energy caused higher differences in these particles released from the Calloway than from the Maury soils. The interaction tillage by energy produced more differences in particle release from aggregates than the interaction soil by energy (Table 3.20), which suggests that aggregation factors were affected by tillage.

The second order interaction (soil by tillage by energy) was only significant in a few cases. When it was significant (Table 3.20), the differences produced by tillage-energy interaction on particle release were higher in the Maury soil than in the Calloway soil. It is interesting to notice that no significance implies that shaking the aggregates in water cannot release more particles than without shaking, despite the effect produced in aggregates by tillage system.

3.2.3. Effect of low and high kinetic energy wetting on particle release at the field scale

Mean comparison from total soil loss can be observed in Table 3.21. Total soil loss was higher in the Calloway than in the Maury soil. With HKE higher total loss occurred than with LKE in both soils and tillage systems. Under CT, the total loss was the highest, and the lowest value was observed in the Maury soil under NT. However, notice that under NT with HKE no difference was observed in both soils and with LKE, CT in the Maury soil and NT in the Calloway had the same total soil loss ($p < 0.05$).

Three-factor analysis for main effects and interactions for all treatments on total soil loss are shown in Table 3.22. The main effects were energy (high and low-wetting energy used when wetting the soil surface), soil (Maury silt loam and Calloway silt) and tillage system (No Tillage and Conventional Tillage). All main effects were significant ($p<0.05$) and their consequences were discussed previously (Table 3.21).

According to the statistical analysis, only the interaction energy by tillage was significant, which means that the differences caused by energy on total soil loss were higher under CT than under NT (Table 3.22).

Table 3.21: Average total soil loss produced by interrill erosion in the Calloway soil and in the Maury soil under conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE).

Energy	Soil			
	Calloway		Maury	
	CT	NT	CT	NT
	-- kg ha^{-1}--			
HKE	$1820_{a,\ 1}$	$290_{a,\ 2}$	$1170_{a,\ 1}$	$250_{a,\ 2}$
LKE	$250_{b,\ 1}$	$70_{b,\ 2}$	$60_{b,\ 2}$	$10_{b,\ 3}$

Abbreviations: letters in same columns and numbers in different rows means significant at $p < 0.05$.

Table 3.22: Three-factor analysis for total soil loss (kg ha^{-1}) from the Calloway and the Maury soils under different tillage and wetting energy treatments.

Source	SS	Df	Mean Sq	F ratio	P
Main effects					
A. Energy	20549.90	1	20549.90	121.23	0.0000
B. Soil Texture	1015.28	1	1015.28	5.59	0.0307
C. Tillage	26911.50	1	26911.50	158.76	0.0000
Interactions					
AB	611.71	1	611.71	361.00	0.0818
AC	12610.20	1	12610.20	74.39	0.0000
BC	39.21	1	39.21	0.23	0.6392
ABC	16.15	1	16.15	0.10	0.7628
Residuals	2034.06	12	169.50		
Total (corrected)	64225.40	19			

Average values and the analysis of variance for release of total particles amount for different size into the sediment produced with low (LKE) and high kinetic energy wetting (HKE) during 1 h of simulated rainfall on the Maury and Calloway soil under CT and NT are shown in Table 3.23. The interaction soil by tillage by energy was significant for the release of particles in the range from 0.053 to 0.105 mm, from 0.105 to 0.250 mm and from 0.500 to 1.000 mm. The differences in the amount of particles smaller than 0.250 mm released from these soils were higher in the Calloway than in the Maury. In case of particles greater than 0.500, the observed differences were higher in the Maury than in the Calloway soil. Tillage by energy interaction and soil by energy interaction confirm that the Calloway soil tended to release more particles smaller than 0.250 mm than the Maury soil.

Repeated measures in time were performed on each of the sediment particles fractions produced in both soils, under CT and NT, with high and low kinetic energy wetting (Table 3.24). Significant results obtained in interaction soil by tillage by energy by time suggested that during the rainfall, the process of particle release were affected. Soil response could be modified for the time that soil was exposed to the water. This hypothesis is supported by data of particles released from aggregates without shaking in water (Table 3.20).

In Figure 3.7 it becomes apparent that the release of particles smaller than 0.053 mm was not a smooth process. Particles were released in a wave-like fashion, rising and falling. In other words, particle release was not progressing in time with a constant rate, and sorting did not seem to follow a definite order. Notice that the duration, magnitude and frequency of peaks did not appear at the same time.

For particles in the range from 0.053 to 0.105 mm (Table 3.24) (Figure 3.8), third order interaction (soil by tillage by energy by time) was significant, which indicated a complex relationship among the factors on particle release of this size during the rainfall.

Loss of this particle size range with time was controlled by three sources of variation. Soil by time or energy by time but tillage by time were not significant in the loss of 0.053 to 0.105 mm particles indicating that temporal particle release depended on

Table 3.23: Average values and three-factor analysis of total amount of particles in the sediment (g m^{-2}) measured in the runoff produced in the Maury and the Calloway soil under conventional (CT) and no tillage (NT) during one hour of rainfall simulation.

Soil	Tillage	Energy	Range of particle size (mm)				
			<0.053	0.053-0.105	0.105-0.250	0.250-0.500	0.500-1.000
Maury	NT	LKE	0.17	0.17	0.04	0.07	0.37
		HKE	0.10	0.10	0.14	0.18	0.58
	CT	LKE	3.72	3.22	3.97	3.98	10.85
		HKE	2.53	2.53	4.50	3.06	43.87
Calloway	NT	LKE	4.03	1.19	0.46	0.93	0.50
		HKE	59.47	8.88	1.77	1.89	2.84
	CT	LKE	21.92	1.60	0.85	7.39	10.38
		HKE	147.51	17.65	10.09	7.24	12.62
Main sources and interactions							
A. Soil			**	***	NS	**	**
B. Tillage			*	***	***	***	***
C. Energy			**	**	**	NS	***
	AB		NS	**	NS	*	***
	AC		**	***	**	NS	**
	BC		NS	**	*	NS	**
	ABC		NS	**	*	NS	**

Abbreviations: LKE= low kinetic energy wetting; HKE= high kinetic energy wetting; NS = not significant; (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

Table 3.24: Probability results from a repeated-measure factor analysis for different particle size classes produced by interill erosion in the Calloway and the Maury soil under CT and NT with high and low kinetic energy wetting.

Effect	Smaller than 0.053 mm	0.053 mm to 0.105 mm	0.105 mm to 0.250 mm	0.250 mm to 0.500 mm	0.500 mm to 1.000 mm
A. Soil	***	***	NS	***	***
B. Tillage	***	***	***	***	***
C. Energy	***	***	NS	**	***
AxB	**	NS	NS	NS	***
AxC	***	***	NS	NS	***
BxC	***	**	NS	NS	***
AxBxC	NS	***	NS	NS	***
Time	***	*	NS	***	***
AxTime	***	NS	NS	***	***
BxTime	***	**	NS	***	***
AxBxTime	***	NS	NS	***	***
CxTime	***	NS	NS	***	***
AxCxTime	***	*	NS	***	***
BxCxTime	***	**	NS	***	***
AxBxCxTime	***	**	NS	***	***

Abbreviations: NS = not significant; (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

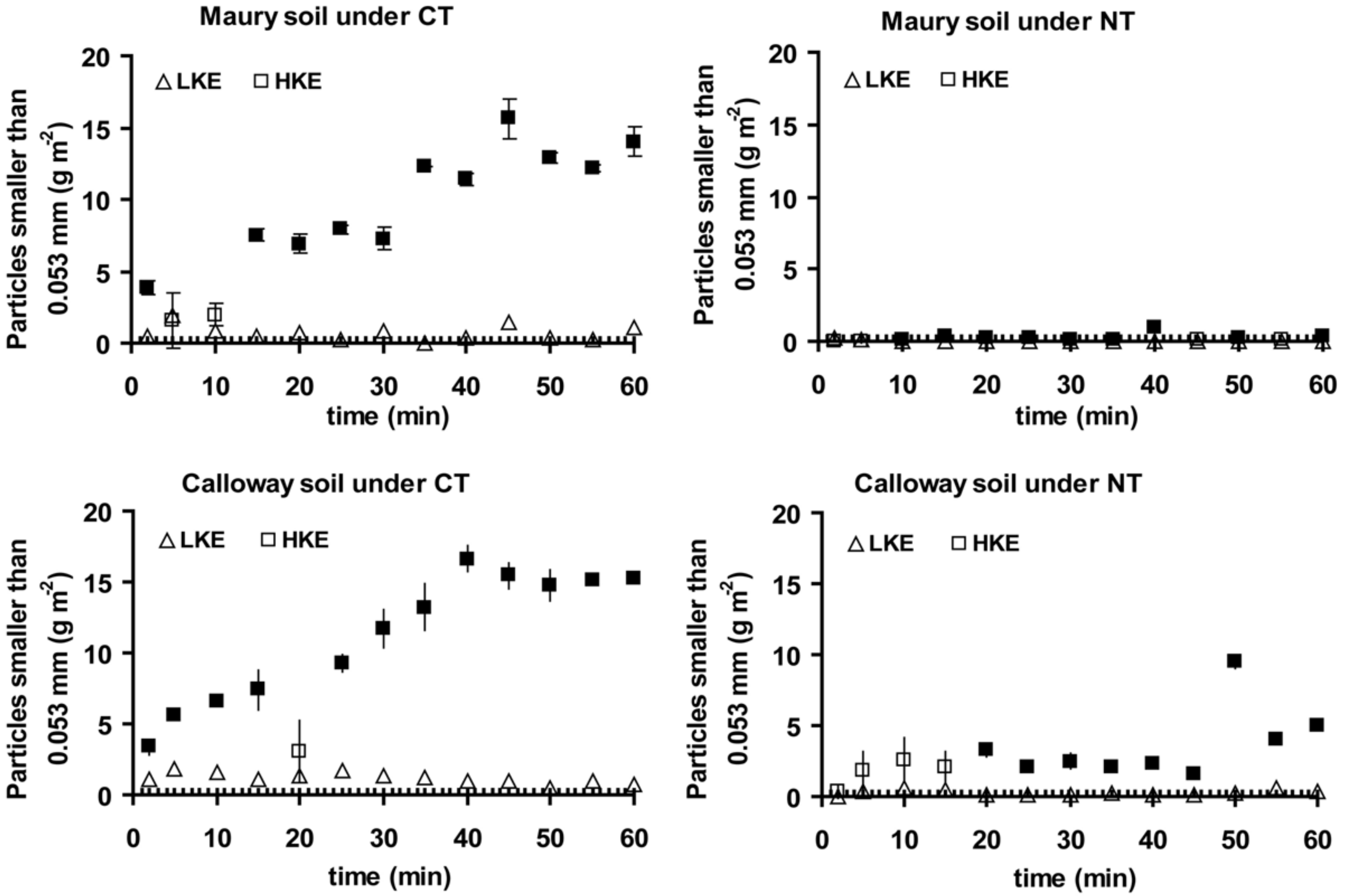


Figure 3.7: Particles smaller than 0.053 mm released in time from the Maury and the Calloway soils under both, conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

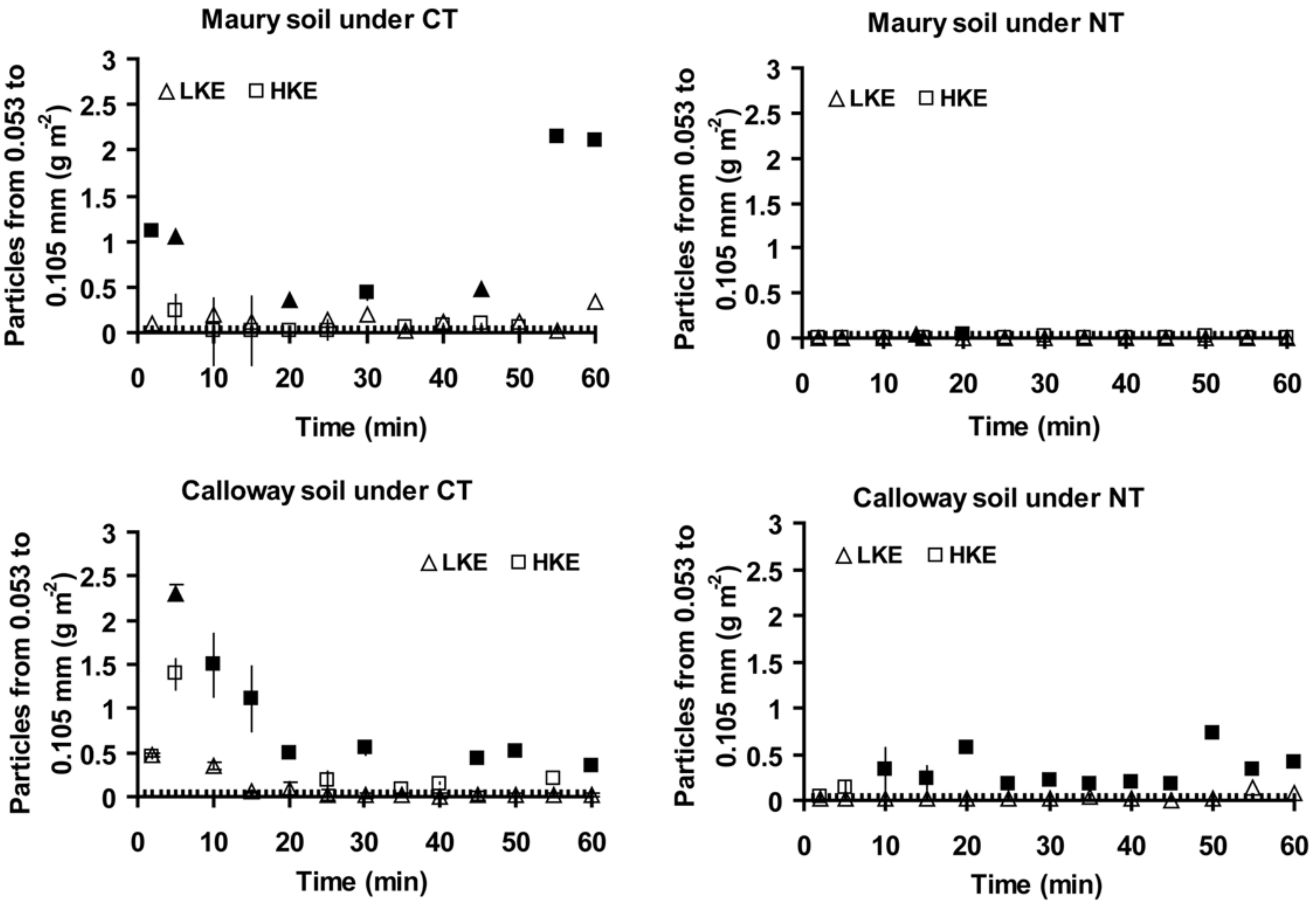


Figure 3.8: Particles in the range from 0.053 to 0.105 mm released in time from the Maury and the Calloway soils under both, conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

intrinsic soil conditions caused by tillage. Conventional tillage caused more soil structure damage than NT, especially in the Calloway soil. In Figure 3.8, because of second order interactions (soil by tillage by energy), differences in particles released with HKE under CT were higher in the Calloway than in the Maury soil.

Detachment of particle range from 0.105 mm to 0.250 mm depended only on the tillage system (Table 3.24). No other statistical significance was observed. The reason why tillage affected this range specifically is not clear, but one reason could be the low aggregation potential of sand-particle sizes.

Particles from 0.250 to 0.500 mm (Figure 3.9) and from 0.500 to 1.000 mm (Figure 3.10) (Table 3.24) behaved during time as occurred with particles smaller than 0.053 mm. Particles from 0.500 to 1.000 mm were significant with all main factors and interactions. However, particles from 0.250 to 0.500 mm were not significant with soil by tillage, soil by energy, tillage by energy and soil by tillage by energy interactions. As a consequence, notice that differences in magnitude of particles released among soil, tillage and energy were reduced compared to the behavior of particles greater than 0.500 mm in size (Figure 3.10). The higher amount of particles from 0.500 to 1.000 mm occurred with HKE under CT in the Maury soil.

Multiple range analysis of particle size classes released in selected time from the Maury soil under both tillage systems, CT and NT is shown in Table 3.25. Under NT with HKE, at 5 minutes after the onset of rainfall, not all particle size classes behaved different but from 20 to 50 minutes, particles smaller than 0.053 mm were the highest ($p<0.05$). Similarly, with LKE at 5 minutes among the particle size classes appeared no differences, but progressively particles smaller than 0.053 mm became higher than the other.

Under CT with HKE at 5 minutes, particles in the range from 0.500 to 1.000 mm were higher than the other particle ranges ($p<0.05$) but at 20 minutes no differences were observed for particles smaller than 0.053 mm. At 30 and 50 minutes, particles smaller than 0.053 mm were the highest. On the contrary, the opposite occurred with LKE, and particles in the range from 0.500 to 1.000 mm were the highest at 30 and 50 minutes. However, particles smaller than 0.053 mm still remained at the second highest values in the particle size distribution, which represents an enormous amount of clay-silt particle size released from this soil.

In the Calloway soil (Table 3.26) under NT with HKE the entire selected period of time but the measurement at 50 minutes were dominated by particles smaller than 0.053 mm. The highest value at 50 minutes was measured in the range of particles from 0.053 to 0.105 mm, but particles smaller than 0.053 mm remained at second level. With LKE, for the entire period of time, particles smaller than 0.053 mm were the highest ($p<0.05$).

Under CT with HKE, the range of clay-silt particle size was predominant all the time. In addition, values measured in this range were the highest measured in both soils. With LKE at 5 minutes, particles in the range from 0.500 to 0.1000 mm were higher than particles smaller than 0.053 mm. After 5 minutes, particles smaller than 0.053 mm remained the highest. These data support the idea that the particle size distribution in the sediment gradually became dominated by particles smaller than 0.053 mm, despite the soil, tillage or energy involved.

3.2.4. Runoff rate, sediment concentration and sediment delivery rate produced with high and low kinetic energy wetting

In Figure 3.11 (a and b) runoff data measured during the rainfall simulation experiment in both, the Calloway and the Maury soil are displayed. Measurement at each time between treatments was compared with the LSD procedure. In the Calloway soil, runoff rate with LKE under CT (Figure 3.11 a) was not different of runoff rate produced with HKE ($p<0.05$) after 25 minutes of rainfall simulation. Under NT, no difference was observed in runoff rate between HKE and LKE after 30 minutes of rainfall simulation (Figure 3.11 a). This result suggested that a strong surface seal was developed with both drop impact (HKE) and aggregate water disintegration (LKE).

In the Maury soil, after 15 minutes under CT and after 10 minutes under NT, runoff rate with HKE was higher than with LKE (Figure 3.11 b). Thus, according to the runoff rate values, while a strong surface seal was developed under CT with HKE,

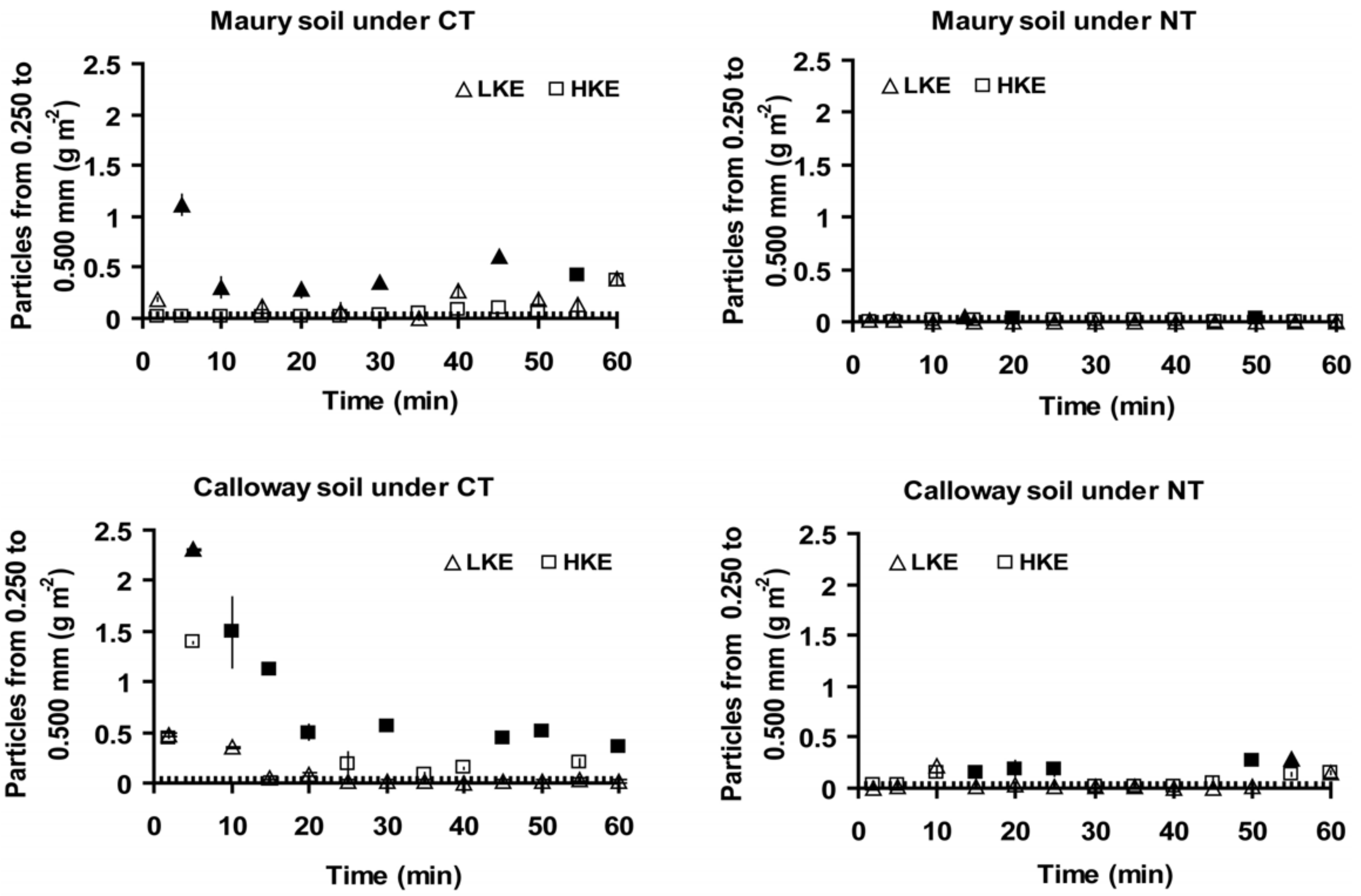


Figure 3.9: Particles in the range from 0.25. to 0.500 mm released in time from the Maury and the Calloway soils under both, conventional (CT) and no tillage (NT), with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

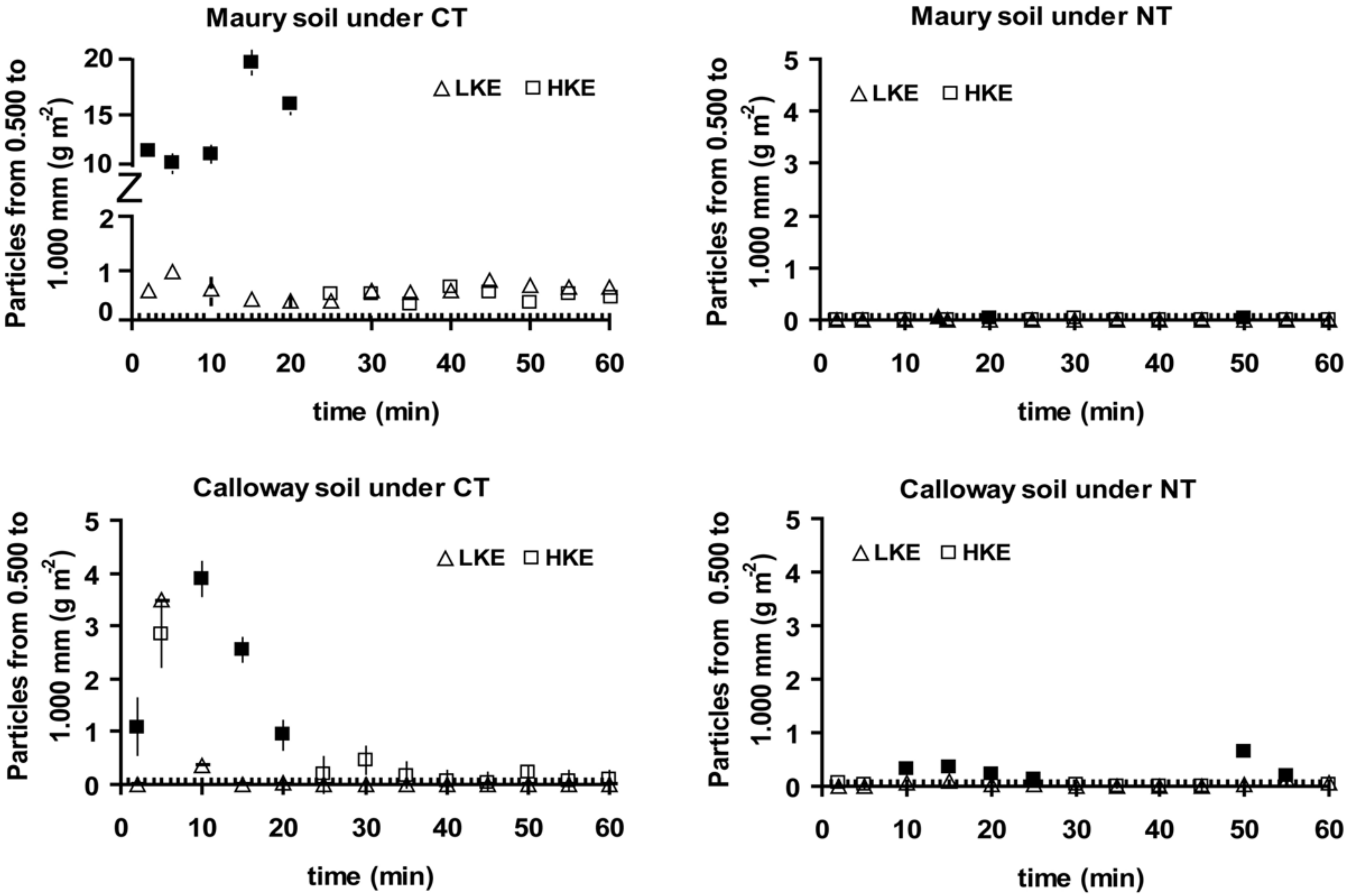


Figure 3.10: Particles from 0.500 to 1.000 mm released in time from the Maury and the Calloway soils under both, conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

Table 3.25: Average values of temporal particle size composition (g m^{-2}) measured in the Maury soil under conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE).

Tillage/Energy	Particles range (mm)	Time (min)			
		5	20	30	50
NT HKE	< 0.053	0.02a	0.21a	0.16a	0.27a
	0.053-0.105	0.02a	--	--	0.02b
	0.105-0.250	0.02a	0.03b	0.02b	0.02b
	0.250-0.500	0.02a	0.03b	0.03b	0.02b
	0.500-1.000	0.02a	0.06b	0.04b	0.10c
		Time (min)			
		5	20	30	50
NT LKE	< 0.053	0.07a	0.02a	0.05a	0.07a
	0.053-0.105	0.02ab	0.04b	0.02a	0.02b
	0.105-0.250	0.02ab	--	--	0.02b
	0.250-0.500	0.02ab	--	--	0.02b
	0.500-1.000	0.06a	0.02a	0.03a	0.03b
		Time (min)			
		5	20	30	50
CT HKE	< 0.053	0.85a	7.59a	5.84a	3.48a
	0.053-0.105	0.12b	0.04b	0.36b	0.06b
	0.105-0.250	0.22b	0.04b	0.04c	0.12b
	0.250-0.500	0.02c	0.04b	0.30b	0.38c
	0.500-1.000	3.17d	8.83a	0.35b	2.18d
		Time (min)			
		5	20	30	50
CT LKE	< 0.053	1.90a	0.67a	0.84a	0.58a
	0.053-0.105	1.05b	0.36b	0.19b	0.11b
	0.105-0.250	0.95b	0.34b	0.21b	0.16b
	0.250-0.500	1.11b	0.28b	0.35c	0.19b
	0.500-1.000	1.39c	0.25b	1.59d	1.20c

Abbreviations: Letters in the same column mean significant at $p<0.05$.

Table 3.26: Average values of temporal particle size composition (g m^{-2}) measured in the Calloway soil under conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE).

Tillage/Energy	Particles range (mm)	Time (min)			
		5	20	30	50
NT HKE	< 0.053	2.27a	5.62a	3.99a	1.48a
	0.053-0.105	0.26b	1.80b	0.59b	1.30b
	0.105-0.250	0.09c	0.38c	0.05c	0.34c
	0.250-0.500	0.05c	0.33c	0.03c	0.41c
	0.500-1.000	0.03c	0.37c	0.03c	1.02d
		Time (min)			
		5	20	30	50
NT LKE	< 0.053	0.39a	0.13a	0.14a	0.20a
	0.053-0.105	0.05b	0.04b	0.04b	0.06b
	0.105-0.250	0.04b	0.02b	0.06b	0.02b
	0.250-0.500	0.02b	0.04b	0.02b	0.02b
	0.500-1.000	0.02b	0.02b	0.02b	0.02b
		Time (min)			
		5	20	30	50
CT HKE	< 0.053	7.23a	3.54a	12.16a	14.92a
	0.053-0.105	1.14b	0.63b	1.98b	1.11b
	0.105-0.250	1.61b	0.62b	0.65c	0.26c
	0.250-0.500	1.39b	0.50b	0.56c	0.50d
	0.500-1.000	2.85c	0.93c	0.45c	0.23c
		Time (min)			
		5	20	30	50
CT LKE	< 0.053	4.42a	1.38a	1.29a	0.48a
	0.053-0.105	0.13b	0.16b	0.09b	0.03b
	0.105-0.250	0.02c	0.08b	0.02b	0.02b
	0.250-0.500	6.25d	0.09b	0.02b	0.02b
	0.500-1.000	9.81e	0.03b	--	0.02b

Abbreviations: Letters in the same column mean significant at $p<0.05$.

a seal surface did not develop with LKE, which suggested a high aggregate resistance to water disintegration. Notice that under NT, runoff rate with HKE was higher than with LKE, but runoff rate values were lower than measured under CT with LKE. This suggested a strong aggregate resistance under NT, which resulted in a weak surface seal.

Runoff rate was analyzed with repeated measures in time statistical procedure (Table 3.27). Third order interaction was no significant but the second order interaction (soil by tillage by energy) was significant. This means that the effect on runoff rates caused by factors included in the model were affected by time. However, soil by time and tillage by time but not energy by time interactions did influence runoff rate. Not significant interaction energy by time means that both kinetic energy wetting applied in those soils produce an independent result in runoff rate during time. Thus, seal surface developed in those soils was not only a result of drop impact alone but also because aggregates were disintegrated in water without drop impact.

Data of sediment concentration in the Calloway and in the Maury soil are shown in Figure 3.12 (a and b). At each time, measurement between treatments was compared with the LSD procedure. In the Calloway soil under CT with HKE and LKE, sediment concentration reaches a maximum value at 5 minutes and then decreases to maintain a steady state condition. In both tillage systems a high sediment concentration was obtained with HKE at 2 and 5 minutes ($p< 0.05$). Another significant value was observed at 25 minutes under CT but at 20 minutes under NT.

In the Maury soil (Figure 3.12 b), under both tillage systems the highest value was observed at the same time (2 minutes), but sediment concentration only was significant under NT with LKE ($p< 0.05$). In addition, with HKE others values were significant at 5, 15, 20 and 40 minutes. Under CT, HKE were higher than LKE values at 10, 15 and 20 minutes but at 45 minutes, sediment concentration with LKE was higher than with HKE.

An interesting behavior observed in these Figures was that the maximum slope in runoff rate coincided with a decrease in sediment concentration, which suggested a low soil detachment capacity of the overland flow, i.e., despite flow velocity increases, no

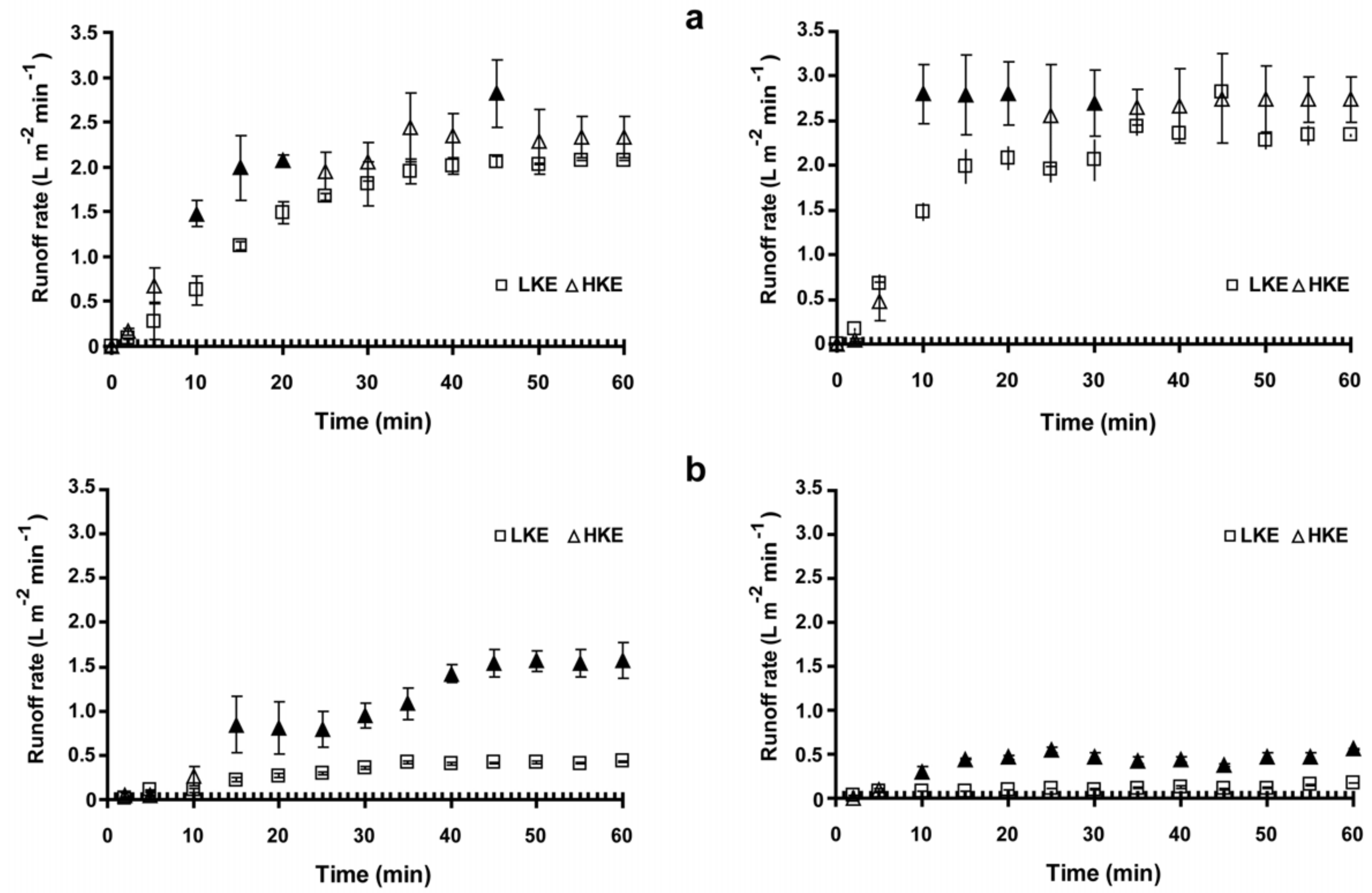


Figure 3.11: Runoff rate measured during 60 minutes of rainfall simulation in the Calloway soil (a) and in the Maury soil (b) under conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

Table 3.27: Probability results from a repeated-measure-factor analysis for runoff rate, sediment concentration and sediment delivery rate (Di) produced by interill erosion in the Calloway and the Maury soil under conventional (CT) and no tillage (NT) with high and low kinetic energy wetting.

Effect	Runoff rate	Sediment concentration	Sediment delivery rate
A. Soil	***	***	***
B. Tillage	NS	***	***
C. Energy	***	NS	***
AxB	***	NS	NS
AxC	NS	NS	***
BxC	NS	NS	***
AxBxC	***	NS	NS
Time	***	***	NS
AxTime	**	**	NS
BxTime	*	*	*
AxBxTime	NS	NS	NS
CxTime	NS	NS	NS
AxCxTime	NS	NS	NS
BxCxTime	NS	NS	NS
AxBxCxTime	NS	NS	NS

Abbreviations: NS = not significant; (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

new particles were detached from the soil surface.

Comparing Figures 3.11 (a and b) and 3.12 (a and b), the maximum sediment concentration values were obtained with at the lowest runoff rates. When runoff rates reached a steady state condition, the sediment concentration also reached a steady state condition. Thus, this behavior suggested a cause-effect relationship. Sediment concentration was significantly affected for soil by time and tillage by time interaction (Table 3.27). However, soil by tillage was not significant, while time as main source was significant. This means that some factor not considered in this analysis probably affected sediment concentration, by modifying the effect of soil and tillage. Due to the fact that sediment concentration depended on runoff rate values, ii can be considered as a factor in this analysis. As was mentioned formerly, runoff was affected for soil by time and tillage by time.

Sediment delivery rate (D_i) measured in the Maury soil under CT and NT with HKE and LKE is shown in Figure 3.13, where at each time data was compared through LSD procedure. D_i values in the Maury soil under CT with HKE were higher than with LKE in all periods except at 5 min (Figure 3.13). Also, it can be observed that with HKE, a particle flush appeared at 2 minutes and another flush appeared at 15 minutes. After that, particle flushes were minimum, and D_i seemed to reach a steady state.

In the Maury soil under NT, during the first 5 minutes D_i values obtained with LKE were higher than D_i obtained with HKE ($p<0.05$). After 5 minutes, D_i with HKE was the highest, except at 55 minutes. Although D_i values in NT were very low compared to CT values, a peak at 15 minutes was still noticeable under NT with HKE, as was observed under CT, thus suggesting a seasonal pattern probably associated with water submergence and drop impact.

Sediment delivery rate in the Calloway soil under CT and NT with HKE and LKE are shown in Figure 3.14. Under CT with HKE, after a flush at 5 minutes, D_i decreased until 20 minutes and then increased to reach a steady state condition. With LKE, D_i showed a peak at 5 minutes and then decreased to a steady state condition. With HKE, Di values were higher than with LKE, except at 5 minutes ($p<0.05$).

Sediment delivery rate (D_i) evaluated through repeated measures in time was displayed in Table 3.27. Soil, tillage and energy as main effects were significant, but time was not. The third order interaction (soil by tillage by energy by time) was not significant, but tillage by time interaction was, which represents the effect of intrinsic characteristics produced by tillage system. One possible tillage effect could be changes in water aggregate stability because this soil property represents a combination among soil physical, soil biological and chemical parameters.

The interaction soil by energy was significant (Table 3.27), thus suggesting that when exposed to different levels of kinetic energy, wetting produced higher differences in D_i in the Calloway than in the Maury soil. In addition, the interaction tillage by energy was significant, and D_i values were higher under CT than under NT. However, no significance was observed in the interaction soil by tillage, thus suggesting a complex relationships with D_i.

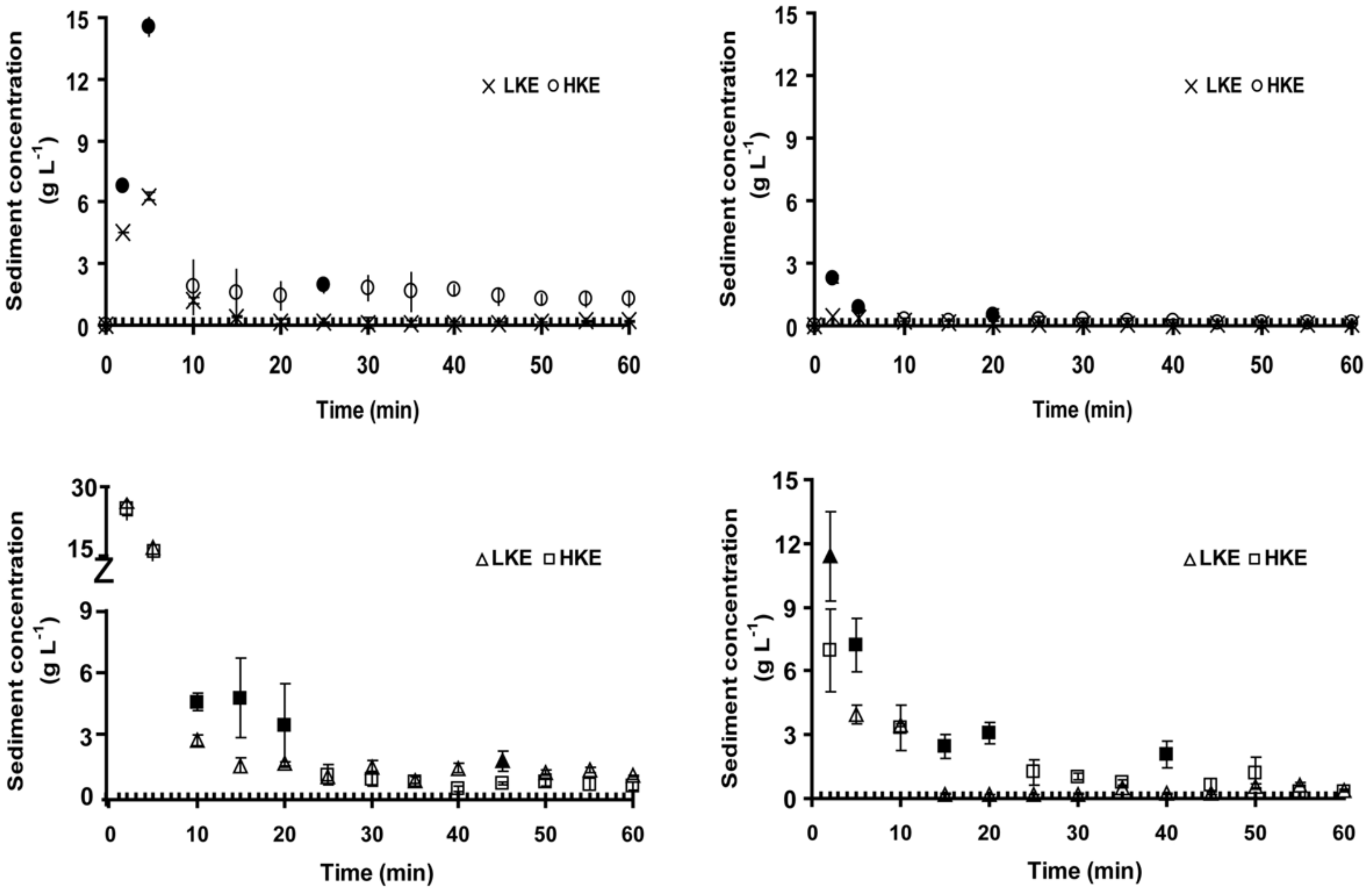


Figure 3.12: Sediment concentration measured during 60 minutes of rainfall simulation in the Calloway soil (a) and in the Maury soil (b) under conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

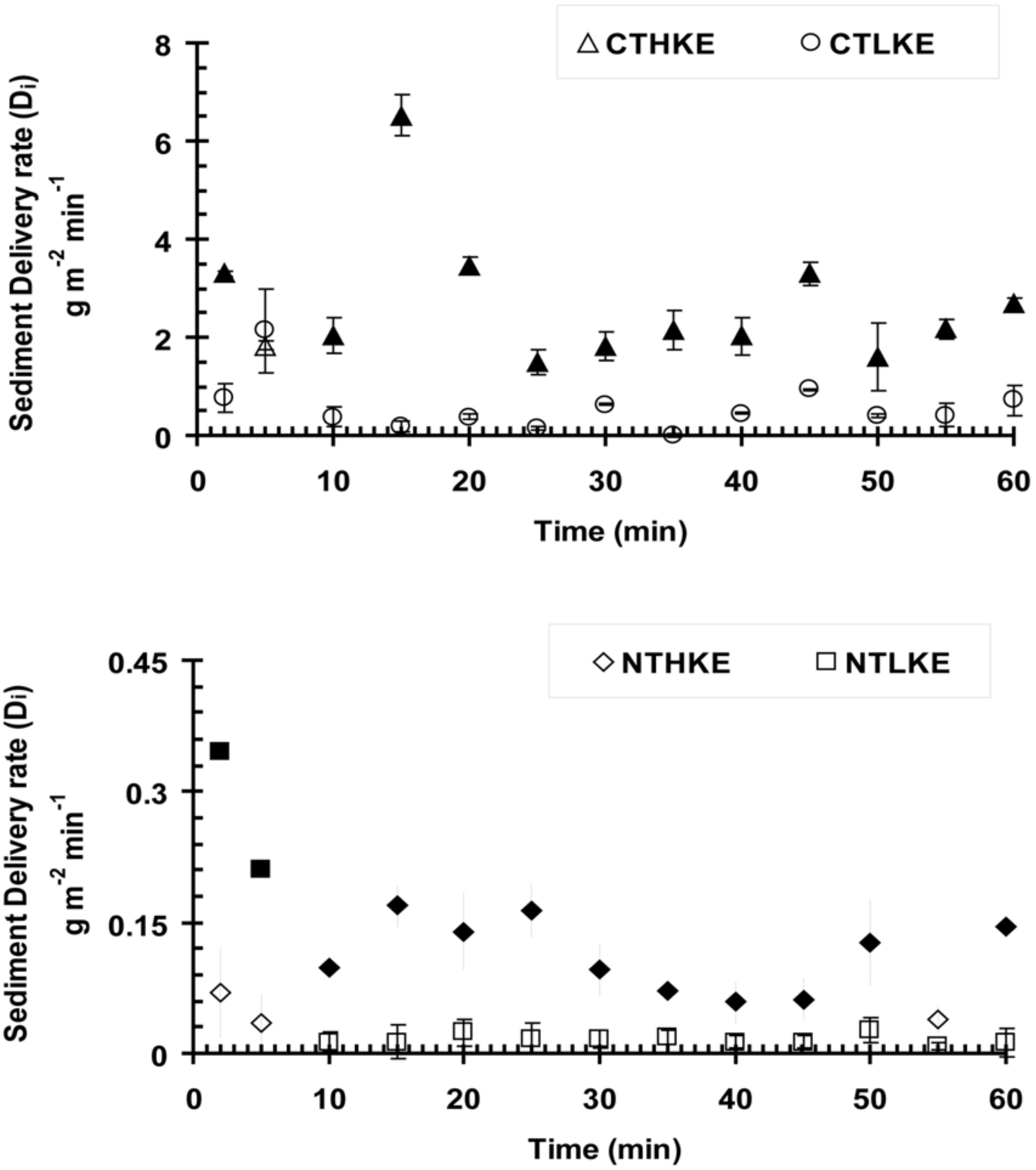
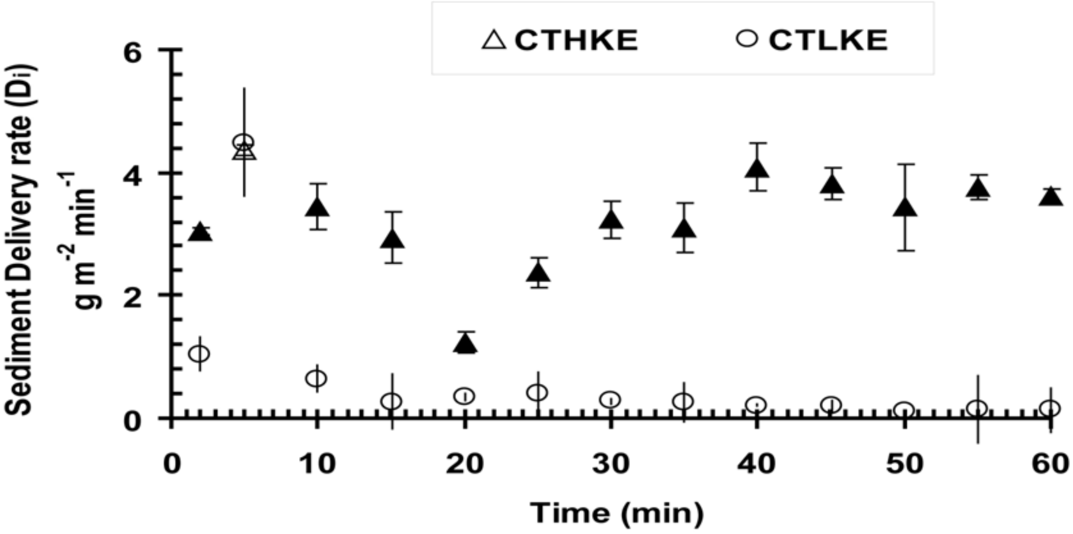


Figure 3.13: Sediment delivery rate (Di) during time in the Maury soil under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p<0.05$.



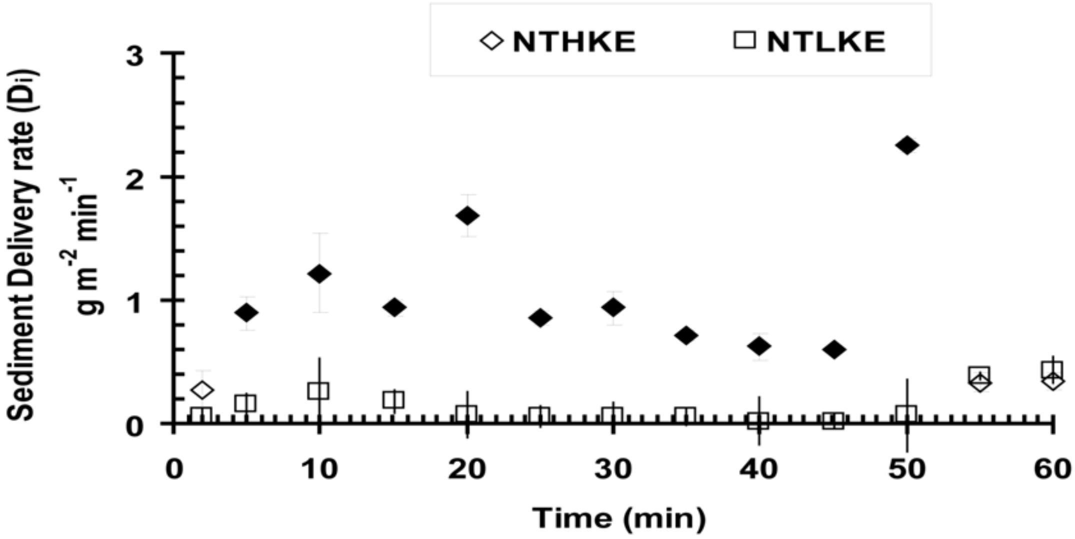


Figure 3.14: Sediment delivery rate (Di) during time in the Calloway soil under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

3.2.5. Total organic carbon content in the sediment

Total organic carbon content in particles smaller than 0.053 mm in the sediment from the Calloway and the Maury soil under both, CT and NT with HLE and LKE can be observed in Figure 3.15 (a and b, respectively). Differences between HKE and LKE for each period were analyzed with a LSD procedure.

In the Calloway soil (Figure 3.15 a) under CT, LKE produced higher values of TOC at 15 minutes and from 25 to 55 minutes ($p<0.05$). Under NT, only a few points produced with LKE were significant in the beginning of rainfall simulation. In the Maury soil under NT, TOC behavior was similar to the one observed in the Calloway soil under NT, but under CT, HKE produced a few higher TOC values than LKE (Figure 3.15 b).

The statistical analysis for the repeated measures in time model for TOC released in different particle size classes is shown in Table 3.28. TOC in different particles in the sediment produced from both soils was generally not a time process, as it can be observed in the third order interaction. In other words, TOC released with particles was not changing in time but remained almost constant during the rainfall.

Energy was a source of variation to the TOC released in particles from 0.053 to 0.500 mm in size. This is especially important for particles smaller than 0.053 mm, because these particles can be exported far away from the release site.

The soil by tillage interaction was significant for all particles sizes but these between 0.053 and 0.105 mm, indicating that tillage had an important effect on TOC release. Due to the fact that under NT in both soils, TOC was always higher than under CT (Table 3.1), this suggested that the higher the TOC concentration, the higher the TOC concentration in particles smaller than 0.053 mm released in the sediment .

The soil by energy interaction was not significant for particles smaller than 0.053 mm, i.e., in both soils, high or low kinetic energy wetting produced the same results.

Because particles smaller than 0.053 mm are a potential environmental hazard, an analysis of enrichment ratio in organic carbon (ER_{OC}) and in organic carbon delivery rate (OC_{DR}) was performed only on this particle size. A complete set of data corresponding to ER_{OC} was included in the Appendix (Tables A4 to A8).

Table 3.28: Probability results from a repeated-measure-factor analysis for total organic carbon (TOC) in different particle size classes produced by interill erosion in the Calloway and the Maury soil under CT and NT with high and low kinetic energy wetting.

Effect	TOC in particles smaller than 0.053 mm	TOC in particles range from 0.053 mm to 0.105 mm	TOC in particles range from 0.105 mm to 0.250 mm	TOC in particles range from 0.250 mm to 0.500 mm	TOC in particles range from 0.500 mm to 1.000 mm
A. Soil	***	***	NS	***	NS
B. Tillage	***	**	***	***	NS
C. Energy	NS	NS	NS	***	NS
AxB	*	NS	***	***	*
AxC	NS	***	**	***	NS
BxC	NS	NS	NS	NS	NS
AxBxC	NS	NS	***	NS	NS
Time	NS	NS	NS	NS	NS
AxTime	NS	NS	NS	NS	NS
BxTime	NS	NS	NS	NS	*
AxBxTime	NS	NS	NS	NS	NS
CxTime	NS	NS	NS	NS	NS
AxCxTime	NS	NS	NS	NS	NS
BxCxTime	NS	NS	NS	NS	NS
AxBxCxTime	NS	NS	NS	NS	NS

Abbreviations: NS = not significant; (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

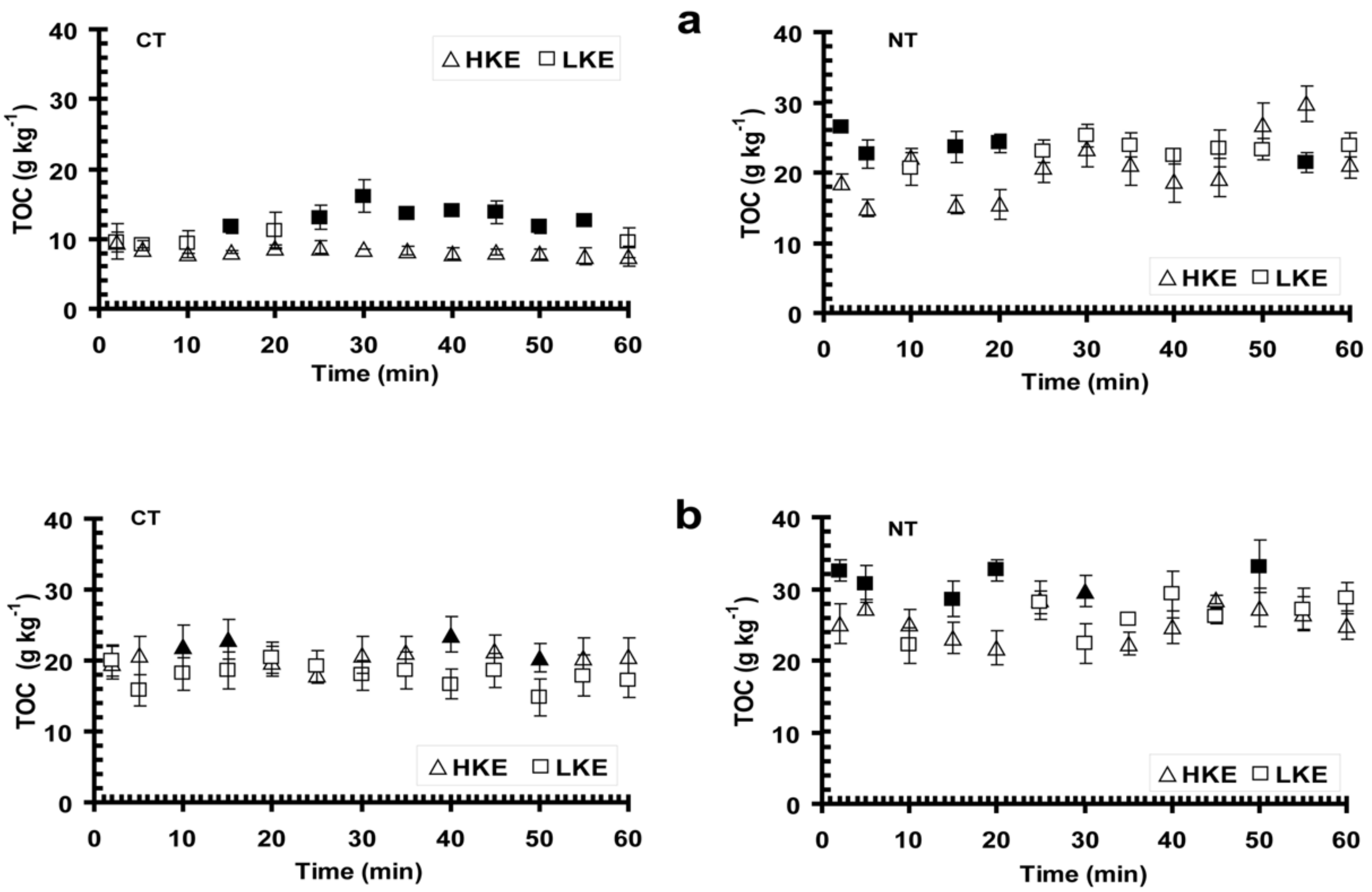


Figure 3.15: Total organic carbon in the particles smaller than 0.053 mm of the sediment collected in the Calloway (a) and in the Maury soil (b) under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

Table 3.29: Probability results from a repeated-measure factor analysis for enrichment ratio in organic carbon (ER_{OC}), organic carbon delivery rate (OC_{DR}) and enrichment ratio in iron (ER_{Fe}) produced by interill erosion in the Calloway and the Maury soil under conventional (CT) and no tillage (NT) with high and low kinetic energy wetting.

Effects	ER_{OC}	OC_{DR}	ER_{Fe}
A. Soil	***	***	**
B. Tillage	***	***	***
C. Energy	*	***	***
AxB	***	***	**
AxC	*	***	*
BxC	NS	***	***
AxBxC	NS	***	***
Time	NS	***	NS
AxTime	NS	***	**
BxTime	NS	***	NS
AxBxTime	NS	***	NS
CxTime	NS	***	NS
AxCxTime	NS	***	NS
BxCxTime	NS	***	NS
AxBxCxTime	NS	***	NS

Abbreviations: NS = not significant; (*) significant at $p < 0.05$; (**) significant at $p<0.01$; (***) significant at $p<0.001$.

The enrichment ratio in organic carbon, was calculated according to equation 9 (Section 2) by comparing TOC concentration in particles smaller than 0.053 mm in the sediment and in soils before the rainfall simulation. Data for both tillage system and kinetic energy wetting in the Calloway and in the Maury soil were included in Figure 3.16 (a and b). Values were compared at each period with the LSD procedure. It can be realized that values of ER_{OC} seem to maintain a steady state condition from the beginning, and it was evident that in the Calloway soil, with LKE, ER_{OC} appeared higher than with HKE after 25 minutes ($p<0.05$) (Figure 3.16 a). In the Maury soil, values were not different under both, CT and NT (Figure 3.16 b). Notice that because ER_{OC} was always higher than 1, this suggested that the particles released were adsorbed to OC during the transport.

The repeated measures analysis for ER_{OC} is found in Table 3.29. Only the soil by tillage and soil by energy interactions were significant, which means that no temporal trend existed in ER_{OC}, the differences were provoked by soil and tillage when exposed to different wetting energy. Because the increase in ER_{OC} was observed even when low kinetic energy was applied, an important release of OC could be expected during every single rain.

Organic carbon delivery rate (OC_{DR}), which was calculated using data of TOC in particles smaller than 0.053 mm and sediment delivery rates measured in the same particle size are shown in Figure 3.17 (a and b). The LSD comparison of data at each period showed that in the Calloway soil and in the Maury soil under both tillage systems, OC_{DR} was higher with HKE than with LKE. Notice the change in scale in different treatments.

The results of the repeated measurement in time (Table 3.29) showed that OC_{DR} in soil was a temporal process and depended on soil characteristics, tillage system and kinetic energy wetting. Third order interaction was significant, which means that OC release had a temporal component, i.e., not only main sources affected OC_{DR}, but also time on water submergence played a role in this process.

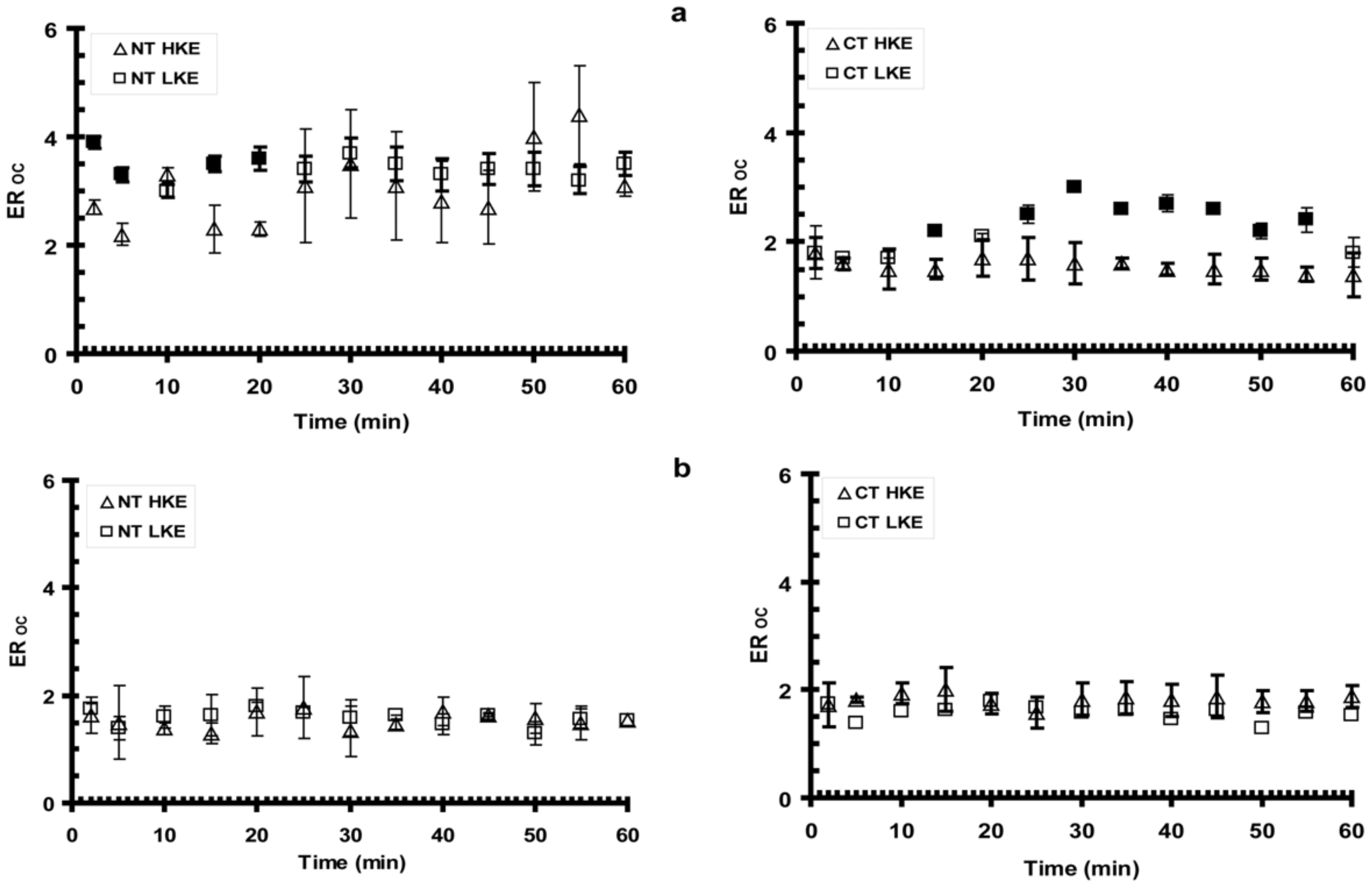


Figure 3.16: Enrichment ratio in organic carbon (EROC) of particles smaller than 0.053 mm in the sediment from the Calloway (a) and from the Maury soil (b) under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

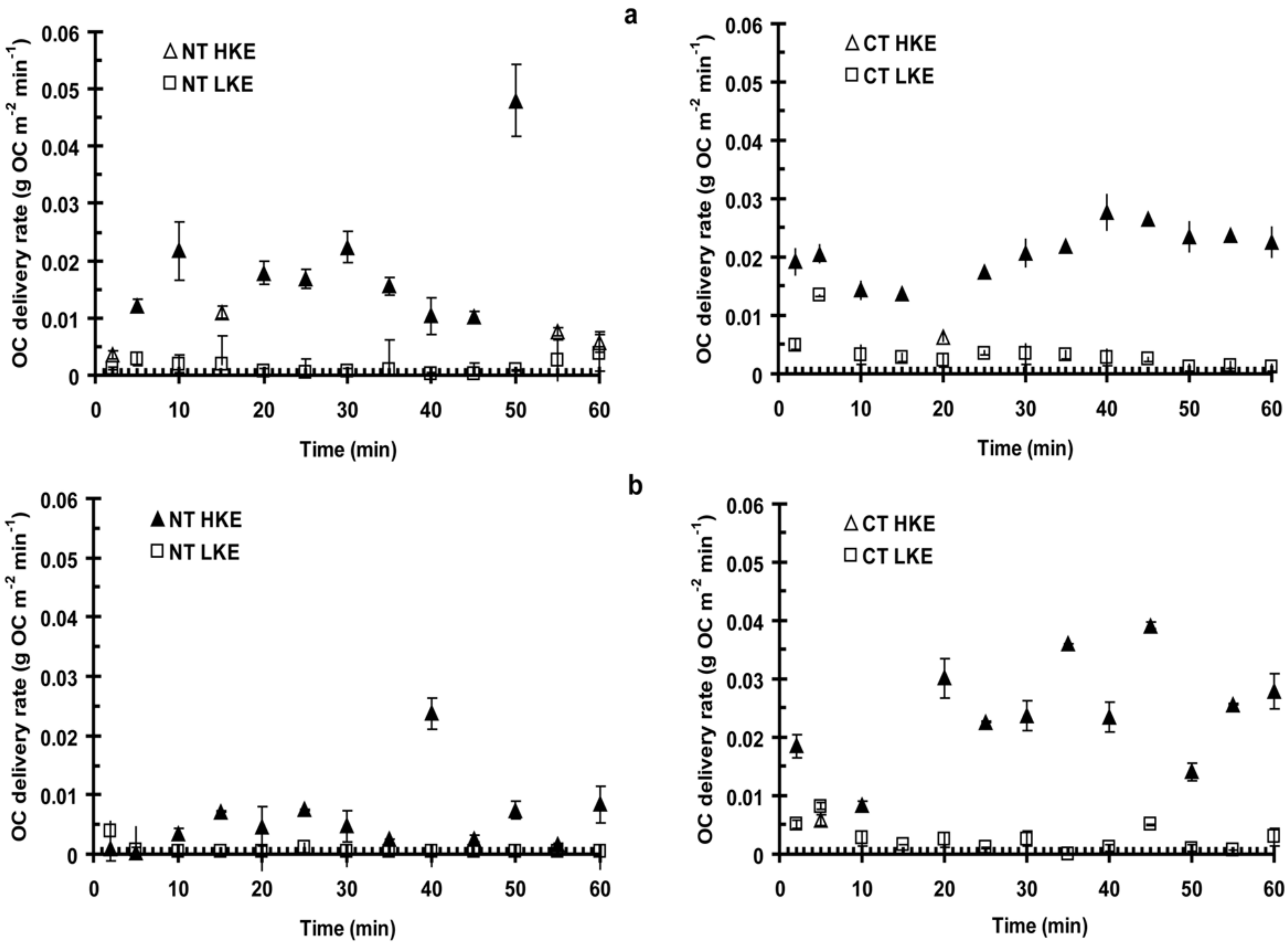


Figure 3.17: Organic carbon delivery rate during time measured in particles smaller than 0.053 mm in the Calloway (a) and in the Maury soil (b) under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significant at $p < 0.05$.

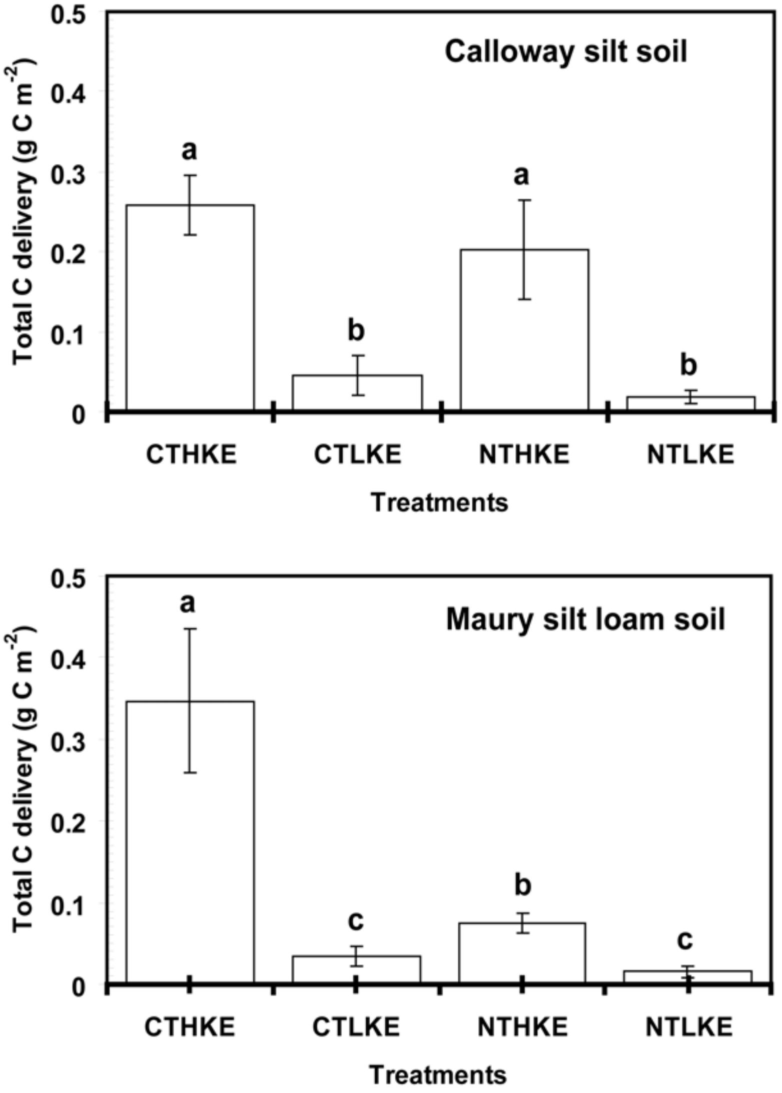


Figure 3.18: Total carbon delivery (TCD) in particles smaller than 0.053 mm in the Calloway and in the Maury soil under both, conventional (CT) and no tillage (NT) with high (HKE) and low kinetic energy wetting (LKE). Bars denote standard deviation. Within the soil different letters represent significance at $p < 0.05$.

Total carbon delivery (TCD), in g C m^{-2}, was calculated by integrating values over time and it was displayed in Figure 3.18. In the Calloway soil, TCD was not influenced but tillage, but only by wetting energy. However, in the Maury soil, both tillage and wetting energy influenced TCD. The highest value of TCD occurred under CT Total carbon delivery (TCD), in g C m^{-2}, was calculated by integrating values with HKE. In other words, in the Calloway soil, high kinetic energy wetting produced no differences in TCD, even with NT, but in the Maury soil, HKE produced much more C delivery under CT than under NT. This implied that under NT, the Maury soil developed aggregate resistance to protect OC, despite being exposed to high levels of destructive kinetic energy.

3.2.6. Enrichment ratio in iron (ER_{Fe}) and total iron delivery (TID) with particles smaller than 0.053 mm

In Figure 3.19 (a and b) ER_{Fe} data from the Calloway and the Maury soil under both tillage and kinetic energy wetting were displayed. The LSD procedure was used to compare data at the same time. In the Calloway soil under CT with HKE during the first 10 minutes, ER_{Fe} was higher than other treatments ($p<0.05$) (Figure 3.19 a). In the other treatments, ER_{Fe} seemed to reach equilibrium very soon, at values between 1 to 1.5. At 20 minutes, ER_{Fe} measured under CT with HKE decreased to reach a value similar to the other treatments, but at 30 and 50 minutes again some peaks appeared ($p<0.05$).

In the Maury soil, ER_{Fe} measured under CT with HKE showing several peaks and the highest one ($p<0.05$) occurred at the end of rainfall simulation (Figure 3.19 b). Notice that also under NT with HKE an important peak appeared at 35 minutes, not different from the value observed under CT with HKE. ER_{Fe} values were higher than 1, which means that an important iron release occurred in both soils. The process seemed to be conditioned for aggregate rupture, according to the patterns observed by comparing HKE with LKE. In addition in both soils at 25 minutes, ER_{Fe} values became similar, as if the process reached an equilibrium.

Enrichment ratio in iron (ER_{Fe}) statistical analysis is found in Table 3.29. Repeated measures analysis found that ER_{Fe} was affected for the soil by time interaction, which means that the principal factor for temporal response of the ER_{Fe} was soil

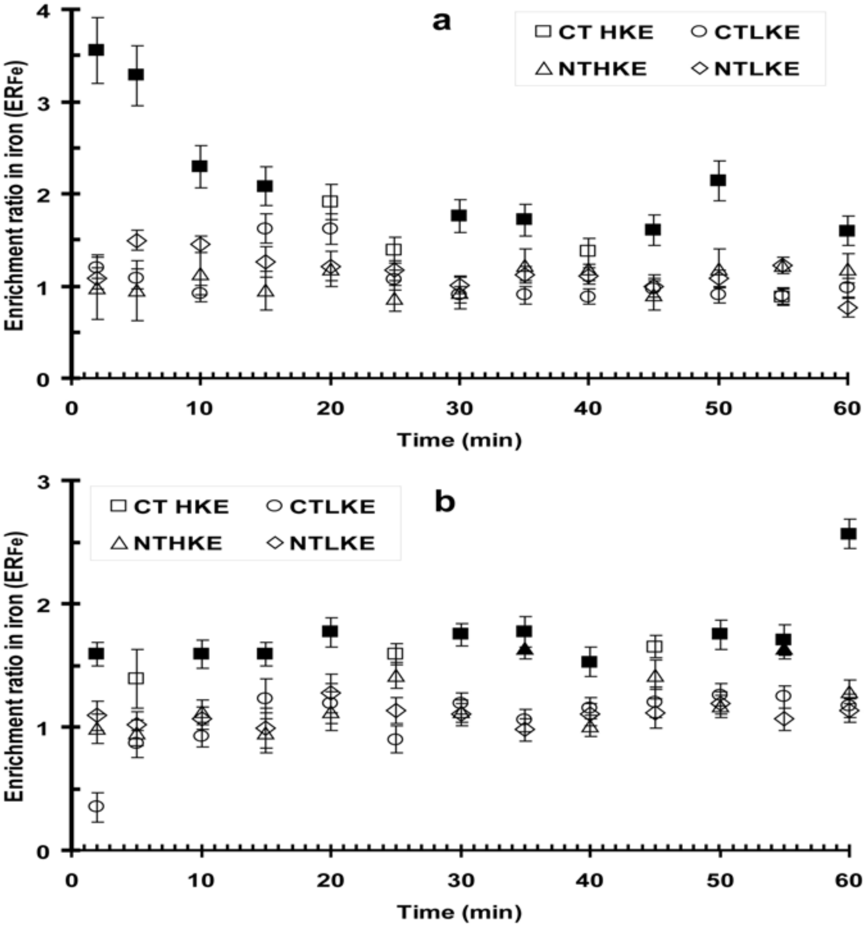


Figure 3.19: Enrichment ratio in iron (ER_{Fe}) during time, measured in particles smaller than 0.053 mm in the Calloway (a) and in the Maury (b) under both, conventional (CT) and no tillage (NT) systems with high (HKE) and low kinetic energy wetting (LKE). Filled symbols represent significance at $p < 0.05$.

characteristics. It was interesting that the second order interaction (soil by tillage by energy) was significant, but the third order interaction (soil by tillage by energy by time), resulted not significant. The differences produced by HKE in ER_{Fe} were higher under CT in the Calloway soil. When time was involved, probably because the period of submergence increased, the differences mentioned in the second order interaction were diminished (Table 3.29).

Data for Fe(ox) measured in particles smaller than 0.053 mm were combined with D_i for the same particle size by integrating values on time in order to obtain total iron delivery (TID) in mg Fe(ox) m^{-2}. This is the total iron mass lost in a single rainfall event, according to the conditions established in this study, and is displayed in Figure 3.20. Both soils under CT with HKE exhibit the highest iron loss ($p<0.05$). Under CT, in the Maury soil, TID was higher than in the Calloway soil (0.46 mg Fe m^{-2} vs. 0.28 mg Fe m^{-2}). Notice that in both soils, TID values were not different under CT with LKE and under NT with HKE, but under NT with LKE, TID was the lowest. This suggested that drop impact was an important factor to release iron in these soils.

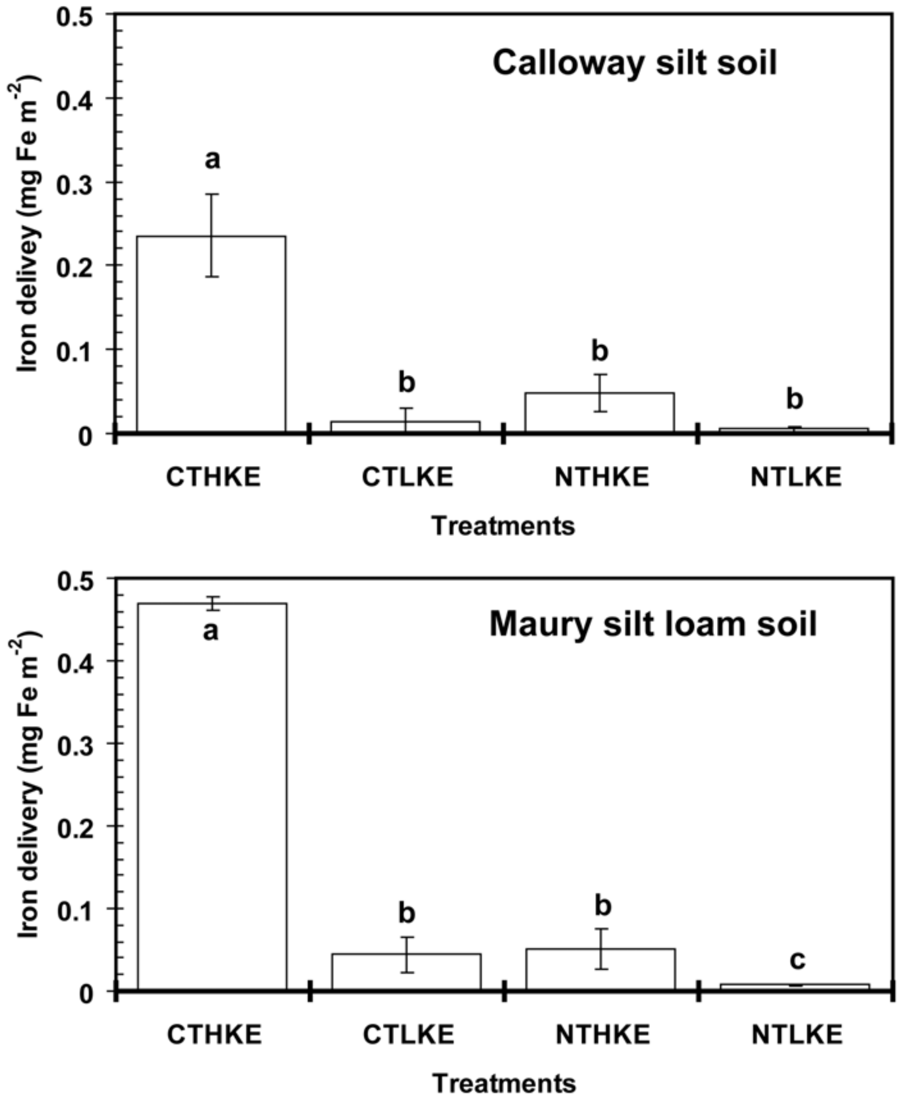


Figure 3.20: Total iron delivery (TID) in particles smaller than 0.053 mm from the Calloway and the Maury soils under both conventional (CT) and no tillage (NT) systems, eith high (HKE) and low kinetic energy wetting (LKE). Bars denote standard deviation. Within a soil, different letters represent differences at $p < 0.05$.

Section 4. DISCUSSION

4.1 Tillage effects on soil properties

Soils in this study differed in their properties. These differences were not only due to intrinsic soil characteristics but also to the effects of different tillage systems. The Calloway soil had higher silt content and lower clay content than the Maury soil, which could have contributed to aggregate instability.

GMD and MWD indices combined with dry aggregate size distribution confirmed that the Calloway soil also had smaller aggregates than the Maury soil under CT. This means that the ability of the Calloway soil to produce large aggregates, which are known to be stabilized by hyphae and root network (Alvaro-Fuentes et al., 2008b), was reduced under CT as opposed to NT.

Reduction in binding agents should provoke an easy breakdown of soil aggregates in the Calloway soil when exposed to different wetting rates. However, water stable aggregates (WSA) showed that the Maury soil under CT was more unstable than the Calloway soil under CT.

Correspondence between different dry soil aggregate distribution indices and WSA was also not mentioned in other studies (Watts et al., 1996; Alvaro-Fuentes et al., 2008b). One reason could be the lack of relationship between aggregate's range from 1 to 2 mm size in WSA procedure of Kemper and Rosenau (1986) and different aggregate size classes in the bulk soil.

In the WSA procedure it is assumed that aggregates in the range from 1 to 2 mm are representative of tillage effects on soil. However, it is known that aggregates have heterogeneity in soil properties (Jasinska et al., 2006; Adesodun et al., 2007), which can affect the way they react in water.

Total soil organic carbon (TOC) was higher under NT than under CT in both soils (Table 3.1), but the difference between NT and CT was more pronounced in the Maury soil than in the Calloway soil. Several researchers found that TOC tends to increase in the soil surface under NT (Lal et al., 1990; Unger et al., 1991; Franzluebbers and Arshad, 1996; Limousin and Tesier, 2007). Our results support this finding and TOC content was larger under NT than under CT (Table 3.1).

In addition, in spite of different length of time under their particular tillage system, under CT both soils have similarly low values in TOC, but the reason for this behavior is not clear. Probably, different crop rotations could be responsible for this finding. Crop residues and root distributions were different in quantity and quality, as well as OC chemical compounds, especially when corn is compared with soybeans (Dinel et al., 1998; Martens, 2000; Trinder et al., 2009).

TOC is a generic measurement, which includes all kinds of OC present in soil (Jenkinson and Rainier, 1977; Cambardella and Elliott, 1992; Degens et al., 1996; VanderBygaard and Kay, 2004). Several studies (N'Dayegamine and Angers, 1993; Martens, 2000; Abiven et al., 2007) mentioned that fine roots, hyphae, fungal exudates or humic compounds could play a role in soil aggregation. For example, it was mentioned that particulate soil organic matter (POM-C), which is a labile intermediate form between fresh organic materials and humified soil organic matter (SOM), was more sensitive to changes in soil management than SOM (Paul et al., 2004). In addition, it was found that POM-C also was useful to detect soil structural changes in crop rotations (Pikul et al., 2007). Positive relationships observed among TOC, GMD and MWD data suggested that TOC could be an important aggregation factor in these soils. However, no relationship was found between TOC and WSA.

This result supports the idea that only specific groups of OC, being part of TOC, stabilize aggregates. In some studies, Six et al. (2004, 2006) and Abiven et al. (2007) mentioned that some OC compounds increased the water aggregate stability by increasing the aggregate's hydrophobicity (Six et al., 2006; Abiven et al., 2007), whereas other studies found that polysaccharides are hydrophilic and could have the opposite effect (Chenu, 1989).

Hydrophobic organic residues coat soil particles and reduce direct contact between water and soil minerals. Wetting properties sometimes depend on adsorbed organic films only one molecule thick. When these films are removed, the mineral surface can be easily wetted and mobilized (Ellies et al., 2005).

The random nature of this combination of hydrophobic and hydrophilic factors in soils may determine a complex relationship between WSA and TOC. For example, it was mentioned that in a clay loam soil, TOC explained 70 to 90% of variability in soil aggregate stability caused by tillage (Mbagwu and Bazzoffi, 1998). Conversely, Pikul et al. (2007) found a very low relationship ($r^2 = 0.49$) between WSA and TOC.

No relationship observed among TOC, WDC (the amount of free colloids) and clay content (Table 3.1) also suggested that only a specific form of OC could be associated with clay particles to built aggregates. It is known that the basic units of soil aggregates are clay particles, soil organic matter and polyvalent cations (Edwards and Bremner, 1967). This basic concept was used to elaborate the hierarchy model of micro and macro-aggregation (Tisdall and Oades, 1982). A hierarchical model, with different modifications, became the actual referential model to analyze the relationship between soil aggregation and TOC (Cambardella and Elliott, 1992; Gale et al., 2000a; Six et al., 2004; Abiven et al., 2007).

In brief, the hierarchical model (Tisdall and Oades, 1982) consists of three main orders: clay micro-structures (<2 um diameter); microaggregates (2–250 um diameter); and macroaggregates (>250 um diameter). In clay microstructures, clay–organic matter complexes are stabilized by humic acids and inorganic ions (e.g., Ca). The mechanisms involved in the Ca-organic interactions are assumed to be 'cation bridging' mechanisms (Edwards and Bremner, 1967; Tisdall and Oades, 1982; Muneer and Oades, 1989). Tisdall and Oades (1982) proposed a model suggesting a mechanism which could form bridges of polyvalent cations between clay particles surface or hydroxy polymers and the ligand groups of organic polymers, e.g., carboxyl groups, which exist in particles <250 um diameter.

Microaggregates are stabilized directly by microbial materials such as polysaccharides, hyphal fragments, and bacterial cells or colonies (Cambardella and Elliott, 1993a; Carter et al., 2003). The formation of macroaggregates and their temporary stabilization could be the result of a combination of mechanisms related to plant roots and activity of soil fungi and fauna.

The DASD showed that the Maury soil has aggregates larger than the Calloway. In the Maury soil, 50 percent of size distribution was dominated by aggregates smaller than 3 mm. In the Calloway soil, under NT a similar distribution as in the Maury soil was observed, but under CT, 50 percent of DASD was built with aggregates smaller than 1 mm. This suggested that the Maury soil developed a more complex hierarchy model than the Calloway soil, because more aggregate size ranges implies a wide spectra of mechanisms and groups to maintain particles together.

Soil chemical parameters showed that both soils were different. The Maury soil under CT had the highest Exch. Ca content, low Exch. K content compared to NT and no difference in Exch. Mg was observed with other treatments. The Calloway soil had the lowest value of Exch. Ca under CT (Table 3.7) and Exch. K was lower than in the Maury soil. However, it was observed that these differences had low impact on soil physical parameters.

Correlation analysis showed that only the major cations, like Ca and Mg, were related with aggregation indices (MWD and GMD) (Table 3.8). However, these cations were not related with WSA, which suggested the influence of other factors, like TOC or clay content. A model including TOC and clay content explained a large portion of WSA, and by replacing TOC with POM-C the model response increased. The fact that POM-C is a proportion of TOC, suggested that not all kinds of soil organic matter stabilized the aggregates. This could be the reason why no relationship between WDC and TOC was observed in these soils.

Water dispersible colloids (WDC) are another way to determine evidences of soil weakness. A high amount of WDC always represents soil physical problems, associated with water erosion, low water infiltration rate, crust formation and crop emergence delays (Bajracharya et al., 1992; Rhoton et al., 2002; Shaw et al., 2003).

The Calloway soil under CT tended to disperse more colloids than the Maury soil under CT. Notice that in the Maury soil, the most stable treatment was NT, which has a similar WDC value as CT, the most unstable treatment (Table 3.1). However, the Calloway soil under CT has a similar WDC value, but with less total clay content.

In other words, a large percentage of clay content in the Calloway soil under CT was easy-released clay. Notice that silt + clay content and $Fe_{(ox)}$ were related to WDC. A direct relationship between WDC and $Fe_{(ox)}$ suggested an important aggregating effect of Fe oxides in these soils. The Maury soil seemed to have aggregate stability more associated with TOC than the Calloway soil. This condition can explain why the clay fraction was more labile in the Calloway soil than in the Maury soil. WDC seems to depend on clay content (Kjaergaard et al., 2004b), cations (specifically Exch. Ca and Fe hydroxides) (Seta and Karathanasis, 1996b) and specific bonds with OC (Chenu and Plante, 2006; Deng et al., 2009).

4.2. Tillage effect on soil aggregate properties and their consequences on wetting rate

Individual aggregates were characterized in terms of different soil parameters and tested for both, response to rupture and water content at the time of rupture when low and high kinetic energy wetting was applied. To characterize soil aggregates is important to avoid a source of variability produced by different scale domain, when the objective is to make inferences about the relationship between soil parameters. Aggregate size domains are known to possess an intrinsic heterogeneity from their origin (Kristiansen et al., 2006; Sey et al., 2008).

Recently, in several studies different aggregate soil chemical, biological and physical parameters were evaluated, by recognizing that several uncertainties still exist at the aggregate scale (Kirchhof and Daniel, 2003; Adesodun et al., 2007).

Our data showed that aggregates in the Maury soil maintained lower or the same values of Exch. Ca and Mg as the bulk soil, but in the Calloway soil under CT, Exch. Ca and Mg tended to diminish when aggregate size decreased and the opposite occurred under NT.

Adesodun et al. (2007) observed that Exch. Ca and Mg increased when the aggregate sizes increased in grassland, whereas Exch. Na and K remained practically without differences. Moreover, in cultivated soils they found that exchangeable cation values showed no differences among aggregate sizes, but the values measured were the lowest.

Our data showed also that in both soils under CT, TOC values in different aggregate size classes were maintained at similar levels as those observed in the bulk soil, but tended to increase when aggregate size decreased under NT. POM-C also increased under NT when aggregate size decreased, whereas the opposite occurred under CT.

It is known that TOC largely depends on tillage treatments, which can explain why several studies found a decrease (Cambardella and Elliott, 1993b), an increase (Baldock and Kay, 1987) or no differences in TOC content (Beare et al., 1994) when different aggregate sizes were compared. However, it is a fact that NT determines an increase in TOC in different aggregate sizes (Chenu et al., 2000; Abid and Lal, 2008), as it was found in this study.

In spite of differences found in cation content, a low or a null effect among TOC and POM-C on wetting rate and water uptake was observed when different aggregate sizes were compared with the bulk soil data. In fact, wetting rate seemed to be more affected by soil physical than by soil chemical parameters, and probably organic matter and clay contents are indirectly associated with wetting rate and water content through their effect on porosity, aggregate volume or WSA.

Thus, tillage systems could modify wetting rate in two ways, a direct one, by fracturing aggregates and increasing internal porosity, or indirectly, through the decrease in TOC and consequently by reducing aggregate bindings. However, is not well understood how to isolate these two ways to demonstrate which is the predominant.

Comparison in water uptake caused by tillage with low kinetic energy wetting showed that, in the Maury soil, time of water uptake before rupture decreased when aggregate size decreased. Water content was higher under CT than under NT (Figure 3.3).

In the Calloway soil no differences in water uptake were observed in aggregates of 4.75 and 2.78 mm under CT compared to under NT, but aggregates of 8 mm size showed the same behavior as observed in the Maury soil. Under CT water content was higher than under NT.

By recalling that the wetting rate (k) according to the procedure of Rasiah and Kay (1995) is the slope of cumulative curve of water uptake, the k value for aggregates of 8 mm was not affected by soil but by tillage and energy. Consequently, k values were higher in CT than in NT (Table 4.1).

In aggregates of 4.75 mm both tillage systems produced similar k values in both soils. Also, in the Maury soil no differences were observed in aggregates of 2.78 mm, but in the Calloway, k tended to be higher under NT than under CT.

Eynard et al. (2006) studied this wetting phenomena in soils, and with fast wetting rate, they observed that aggregates retained a high water content. They mentioned that incipient failures formed in the aggregates under tillage were the mechanisms involved.

The underlying assumption was that inside of aggregates some clay cores in contact with water became dispersed and destroyed the aggregate structure.

Microcracks resulted in a high wettability that easily caused collapse in aggregates with an open network of clay domains, as opposed to large and interconnected stable pores observed in natural aggregates from grassland (Eynard et al., 2004). Natural aggregates also have complex bonds, which allow them to resist the slaking forces. Thus, presence of microcracks and a decrease in binding agents are acting together to debilitate aggregate structure under CT. The more intensive the tillage, the more weak the structure becomes, thus a low aggregate stability and a fast wetting rate would favor an aggregate failure and slaking (Eynard et al. 2006).

However, the effect of TOC on wetting phenomena remains unclear. Aggregates of different size presented different relationships between TOC and POM-C. Under NT, values of TOC tended to increase with decreasing aggregate size and to maintain similar low value under CT.

On the contrary, POM-C depended on both, soil and tillage systems. The Maury soil had more POM-C than the Calloway soil, and under NT in the Maury soil, POM-C increased with aggregates of 8 and 2.78 mm, whereas in the Calloway soil, it increased when aggregate size decreased (Tables 3.12 to 3.14).

It is known that OC has complex structures: soluble, partially soluble and non-soluble components (Cambardella and Elliott, 1992; Ellerbrock et al., 2005). In a study about the relationship between chemical composition and wettability, Ellerbrock et al. (2005) found an increase in wettability until 10 g kg^{-1} TOC content and then wettability decreased. They attributed this effect to different OC chemical compositions and the spatial orientation toward mineral surfaces. In particular, this spatial orientation depended on the number of functional OC groups, and exchangeable cations like Ca and Fe.

Our data showed that k/TOC ratio changed with aggregate size. Our TOC values under CT were in the range mentioned by Ellerbrock et al. (2005), i.e., around 10 g kg^{-1} in aggregates of 8 mm and less than 10 g kg^{-1} in aggregates from 4.75 to 2.78 mm. In these cases, wetting rate increased when aggregate size increased. Conversely, under NT, with more than 10 g kg^{-1} TOC, wetting rate tended to decrease when aggregate size decreased.

Ellerbrock et al. (2005) demonstrated a new perspective to analyze wetting rate. It is necessary to improve sampling and chemical analysis procedures, to explore how particular combinations of OC compounds and exchangeable cations could be combined to modify aggregate wettability. This should be the key to control aggregate breakdown and pore stability in saturated or submerged conditions, thus allowing high infiltration rates and low particle release.

Data showed that aggregates exposed to raindrops caused different responses in wetting rates with impact (k_{di}) depending on the aggregate size (Table 3.15). Aggregates of 2.78 mm in both soils under NT had similar k_{di} values, and under CT were higher than under NT. Aggregates of 4.75 mm in the Maury soil showed higher values than the Calloway soil, and in aggregates of 8 mm in both soils the highest values were observed under NT.

It is interesting that in aggregates of 8 mm, all main sources were significant but the interactions soil by energy and tillage by energy were significant for k_{di}. In other words, when exposed to raindrops, NT soil tended to absorb water faster than under CT and the Calloway soil was more affected than the Maury soil. However, all aggregates of 8 mm broke down at the same time. Notice that the Maury soil tended to hold more water than the Calloway soil (Table 3.16), thus suggesting that these aggregates had bonds stable enough to resist the combined mechanisms of kinetic energy and slaking.

When exposed to raindrops, aggregate rupture should be led by forces that resist external stress forces, a process known as friability, which is not the same as occurred with slaking. Also, notice that it is not possible to ignore slaking either, because at the same moment the aggregates are impacted and wetted.

Friability is the tendency of a mass of soil to crumble into a certain size range of smaller fragments (or particles) under the action of applied stress (Dexter, 2004). This theory is based on the concept that the tensile strength and the crumbling of soil are controlled by the distributions of flaws or weakest links within the soil. These flaws may be identified with structural pores or microcracks. Under mechanical stress (especially tensile stress), these flaws can elongate and join up to cause large cracks, which form the boundaries of the fragments produced when the aggregate is broken (Watts and Dexter, 1998).

In general, it is supposed that resistance to external stress increases when the aggregate size decreases, as was measured in a mechanical compression trial (Dexter, 1988). Our data showed that small aggregates retained more water than the large aggregates, but the time to rupture was the same. Large aggregates seemed to be more affected by kinetic energy than by water content, i.e., resistance to external stress was lower than in small aggregates.

When drop impact was involved, splashing effect and drop size/aggregate size ratio played a role in the amount of water that an aggregate can hold before the rupture (Legout et al., 2005). The ratio drop diameter size/aggregate diameter size was 0.65 for small aggregates and 0.22 for large aggregates, thus more aggregate surface was covered in small aggregates than in large aggregates in each impact. This could be the reason why the highest water content was measured in small aggregates.

Notice also that, according to friability theory, a high variability should be expected in aggregate size distribution (ASD) when aggregates are broken, because ASD depends on a random association of cracks into the aggregates. The random nature of this mechanism could explain why a low correlation was observed with soil parameters, like TOC or clay content.

4.3. Effect of wetting rate on sediment produced in rainfall simulation

In the field study, rainfall simulation performed on these soils showed that total soil loss was a function of the kinetic energy wetting applied, as well as of soil type but not a function of the tillage system. Total loss of particles smaller than 0.053 mm were not different in the Maury soil under CT with HKE and LKE compared to the Calloway soil under NT with LKE, thus suggesting that significant interaction of soil by energy overcame the effect of tillage.

Maintaining a low-energy wetting process seems to reduce total soil loss with an increase in selectivity of finest particles. During the rainfall, the finest particles in the sediment are dominating the particle size distribution at 50 minutes, as was observed in Table 3.25 and 3.26.

This behavior was mentioned in several studies (Legout et al., 2005; Issa et al., 2006). Wan and El Swaify (1998b) were working with a Wahiawa Rhodic Eutrustox silty clay soil in an area of 10.2 m^2 and a slope of 4.2%. They found a sediment concentration between 1.7 to 3.5 g L^{-1}, with 70 to 90% of finest particles (<0.063 mm) in the sediment, suggesting that this occurred because of high soil clay content (Wan and El-Swaify, 1998b). In our experiment it was observed that sediment concentration was equilibrated around 0.3 to 2 g L^{-1}, however the release of particles smaller than 0.053 was a consequence of a complex interaction among soil, tillage, energy and time, not because the clay content was different in both soils.

Both Maury and Calloway soils have different clay, silt and sand content (Table 3.1), but total amount of particles smaller than 0.053 mm released was higher in the Calloway with HKE than in the Maury soil. However, the Maury soil had higher clay content than the Calloway (23 to 26 g 100 g^{-1} vis a vis 11 to 13 g 100 g^{-1}). Thus, soil clay content was not the reason for this increase in particles smaller than 0.053 mm in the sediment.

Data revealed that particle release occurred in pulses or flushes, not only with particles smaller than 0.053 mm but with all particles measured in the sediment. When both total soil loss and temporal soil loss were analyzed together, a temporal unknown factor emerged, which was not considered before. Notice that during rainfall simulation, the soil did not only become saturated but also remained submerged. This condition exposed the soil to a long water-solvent action.

Soil submergence increases with time under rainfall, which affects soil stability and particle release in a different way, in accordance to soil aggregation factors. When submerged, internal soil aggregate strength would be exceeded before particle release begins. This particle release will depend on an intrinsic particle's bond that pre-exists in each soil and tillage system before the rainfall. For example, if more particles are linked with hydrophobic rather than with hydrophilic organic components, due to the fact that hydrophobic organic components are not easy to solve in water, less particle release should be expected than in the opposite case.

An idealized and simple scheme was drawn to illustrate this point (Figure 4.1). In this scheme, an aggregate is shown like an arrangement of particles bonded with different hydrophobic and hydrophilic organic components. As an example, in one aggregate side particles are linking with hydrophobic component, represented by several lines. These simple lines represent hydrophobic organic components that are coating particles fully or partially, while in the other aggregate side particles are linking with hydrophilic components. For convenience, in this aggregate side particles were colored (Figure 4.1 a). Sequence of aggregate disintegration starts when the hydrophilic components were solved, and some particles were released (Figure 4.1 b to d). Notice that the idealized scheme of particle release displayed in Figure 4.1 also can explain why sometimes during the rainfall, some particle size classes suddenly appear and disappear in the sediment particle-size class distribution. Sediment detachment for the submerged soil is the result of two mechanisms including fluvial shearing (i.e., turbulent scour) and water disintegration of aggregates. The scour mechanism occurs when a detached particle reaches the point when the flow forces overcome the resisting forces represented by submerged particle weight (Chang, 2002) (Figure 4.2). Another reason could be this bond-dissolution mechanism, especially when particles are not detached yet. This mechanism could not only produce particle detachment in the submergence stage, but could also disintegrate a detached particle and produce several small ones. Consequently, a flush of particles of any size can appear at any time during the rainfall.

Runoff rate and sediment concentration showed another view of the same mechanism. Data showed that while runoff rate increased sediment concentration decreased. One reason for this behavior could be that at the initial stage of rainfall simulation, HKE drop impact produced a maximum detachment from soil surface and removes loose particles that were already located at the soil surface before the rainfall started.

On the contrary, with LKE, only loose particles and those produced by water-aggregate disintegration are mobilized for shallow overland flow. After all loose particles were removed only the new particles produced by water-aggregate disintegration could maintain sediment concentration.

After the initial stage with HKE, the process reached a situation where direct raindrop impact on soil was prevented by overland flow, which absorbed kinetic energy of drop impact (Asadi et al., 2007a). This reduces the amount of energy remaining to produce soil detachment, to the action of turbulence and aggregate disintegration by water. This process could be considered as a mixed mechanism of turbulence plus aggregate disintegration. As a consequence, sediment concentration should be reduced during time, as was observed in Figure 3.12. For example in the Maury soil under CT with HKE sediment concentration drops from 14 to 2 g L^{-1}.

In addition, the mixed mechanism proposed to explain particle release with HKE, indicates that the sediment concentration should be higher with HKE than with LKE. In Figure 3.12, sediment concentration with HKE was always higher than with LKE.

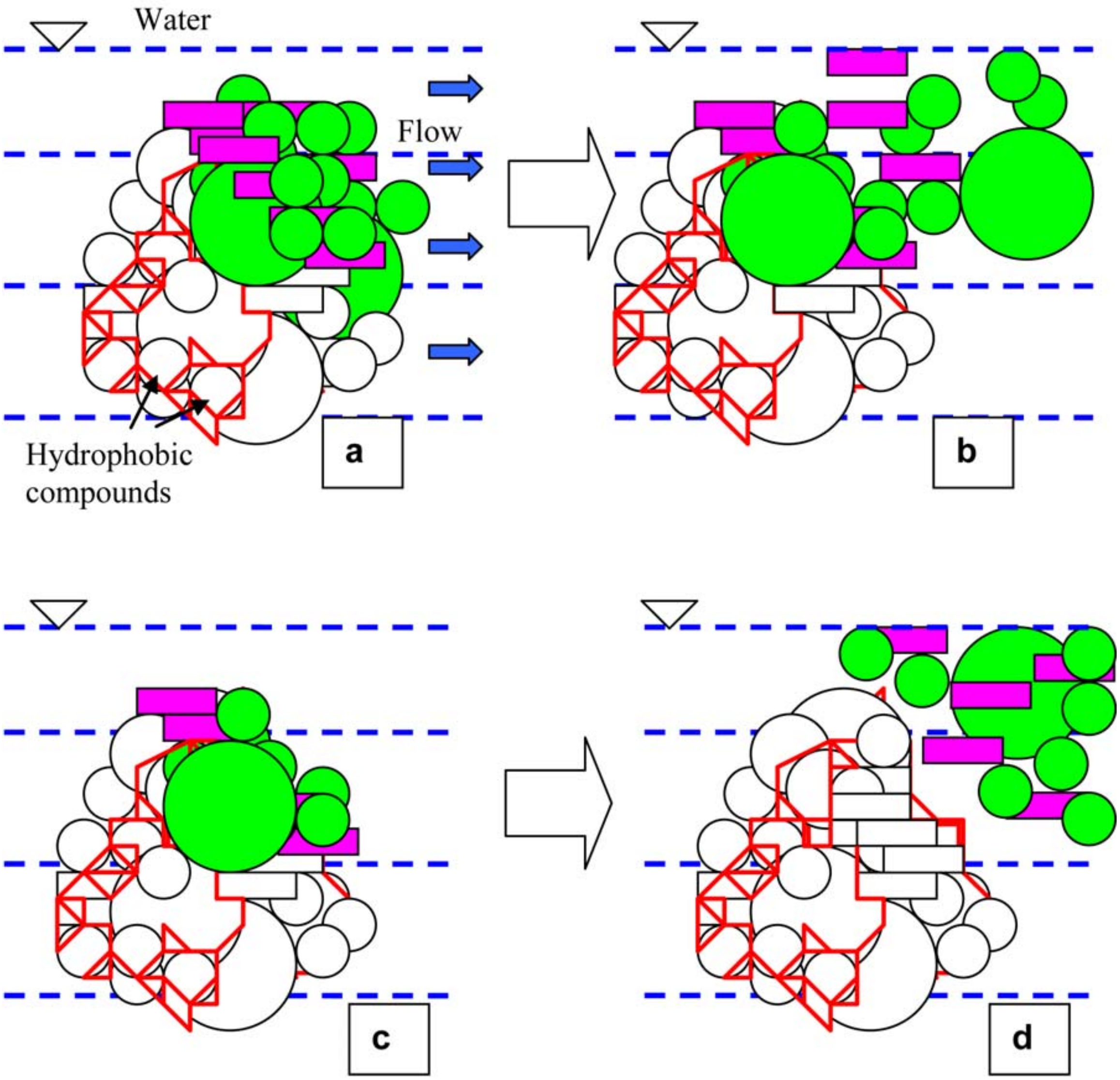


Figure 4.1: Idealized scheme of particle size released from a soil aggregate with hydrophobic and hydrophilic bonds, submerged in water during a period of time: a) A soil aggregate shown particles bonded with hydrophobic compounds. In colors, a group of particles bonded with hydrophilic compounds. b) Particle's release begins when hydrophilic compounds are dissolved, c) new particles linking with hydrophilic bonding are exposed, and d) particle's release continue, while hydrophobic compounds still are holding the aggregate.

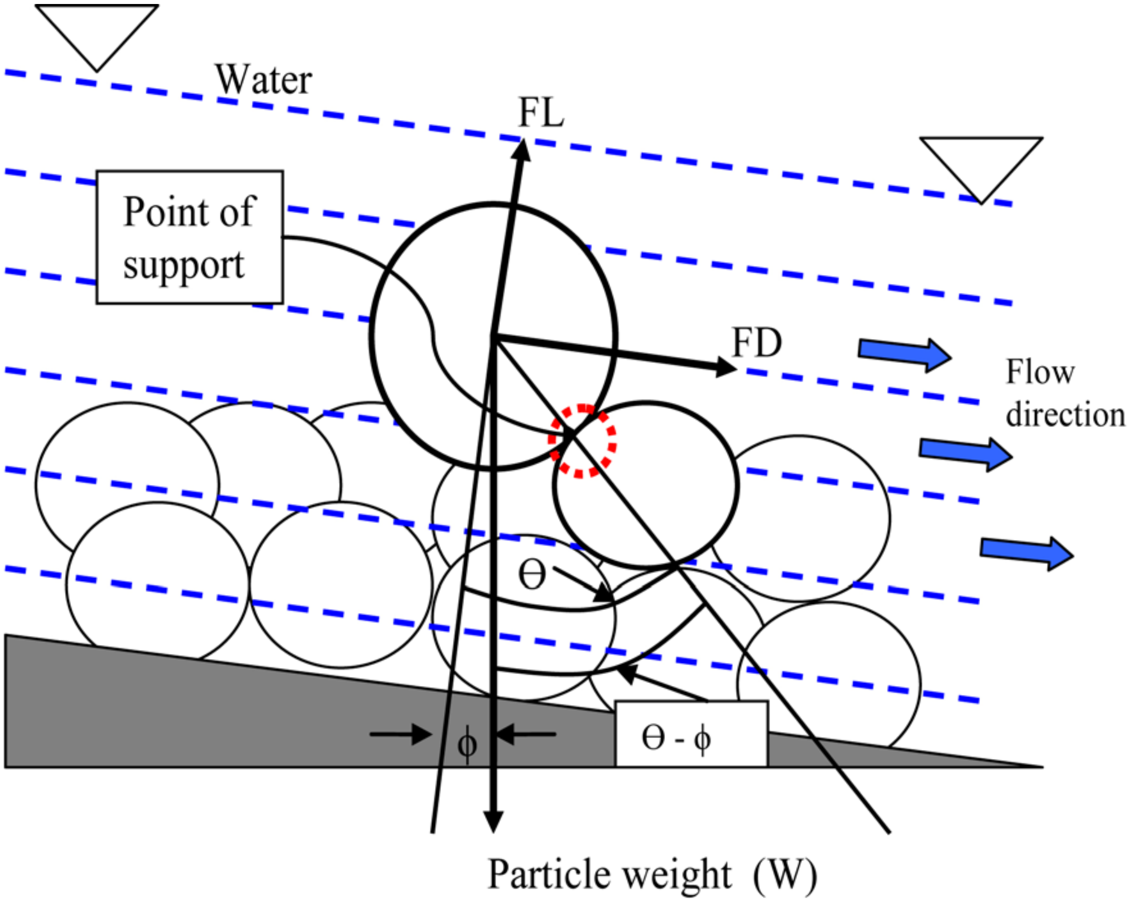


Figure 4.2 : Scheme representative of scour mechanism on a submerged particle. FD is hydrodynamic drag, in flow direction and FL is hydrodynamic lift, normal to the flow. Angle Θ is angle of repose and angle ϕ is the slope angle of surface bed.(Adapted from Chang, 2002).

4.4. A model to explain sediment delivery rate behavior in soils

Sediment delivery rate (D_i) showed a different behavior in the Calloway soil as compared to the Maury soil. The Zhang equation (Zhang et al., 1998), which was proposed to describe D_i, failed for both soils (Figure 4.3). D_i data in the Calloway soil (Figure 4.3 a) and in the Maury soil (Figure 4.3 b) were not properly predicted by this equation for the first 30 minutes of the experiment.

To analyze the variability of sediment delivery rate, an empirical model was fitted to the data in Figure 4.4 in order to show the non-equilibrium sediment peaks in the dataset and illustrate the deviation from Zhang's model. The behavior of the empirical model is shown in Figure 4.4. Notice that the Zhang model assumes equilibrium transport. However, D_i data showed that in both soils, a non-equilibrium stage occurred before an equilibrium was reached (Figure 4.3 a and b). To properly describe this non-equilibrium transport should be an important improvement for this prediction equation.

In the Calloway soil, only one particle flush appeared at the beginning of sediment delivery process, which seems to be associated with the effect between kinetic energy and dissolution. At this stage, loose particles, kinetic energy-detached particles, and particles released from the aggregates as a result of bond-dissolved mechanisms were transported by a shallow overland flow. Gradually, particles from different areas reached the plot's outlet and delivery rate reached a maximum. Thus, non-equilibrium initial stage depended on physical aggregate disintegration and physicochemical dissolution. The Calloway soil showed a weak behavior in water, as was observed in Table 3.20. With and without shaking in water, more than 50 percent of total particles released were smaller than 0.053 mm.

When sediment delivery rate reached equilibrium, this process could be described by the Zhang equation. This equation established that D_i is led by runoff. The Zhang equation should be improved by including a time-related term as follows:

$$D_i = -C_2(t + \{t + dF_1\})^2 + C_1\left(t + \left\{t_0 + \frac{dF_1}{2}\right\}\right) + 0 + k_i I q_c S^{\frac{2}{3}} \qquad (13)$$

where D_i is the sediment delivery rate, the polynomial term to the left accounts for the first flush during time, where dF_1 is flush extent, C_1 and C_2 are statistical coefficients and *t* is time. The last term is the original Zhang equation (Figure 4.4 a). In this way, after the first flush, D_i should be reduced until the runoff rate increases enough to reach the equilibrium. Table 4.1 shows how the prediction increased by comparing the increment in r^2 (0.21 to 0.70) and the reduction in mean absolute error (0.7 to 0.4) obtained with the Zhang equation and with the modified Zhang equation, respectively.

On the contrary, in the Maury soil after the first particle flush aggregates were protected or stable enough to resist the drop impact. A new threshold should be reached before a new flush of particles appeared. This second flush could be caused for detached particles and dissolution of aggregates probably from soil layers not exposed to the direct impact of rainfall. Notice that duration of both fluxes is approximately 10 minutes, which is similar to the time to rupture observed in the aggregate wetting test. This suggests that wetting rate could be involved in producing these flushes.

To predict this behavior with the Zhang equation, two polynomial terms were used to describe both flushes, as follow:

$$D_i = -C_4\left(t_0 + dF_2\right)^2 + C_3\left[t + \left(t_0 + \frac{dF_2}{2}\right) + De_{dF_1}\right] + k_i I q_c S^{\frac{2}{3}} \qquad (14)$$

$$De_{dF_1} = -C_6(t + \{t + dF_1\})^2 + C_5\left(t + \left\{t_0 + \frac{dF_1}{2}\right\}\right) + 0 \qquad (15)$$

Equation 14 differs from equation 13 because it includes two parabolic terms, which take into account both, first and second flush before to reach the equilibrium. Term t_0 is time when runoff begins, t_e is time until runoff equals equilibrium, De_{dF_1} is delivery rate value at the end of the first flush, dF_1 is the first flush extent and dF_2 is the second flush extent (approximately 10 minutes for both), C_3, C_4, C_5 and C_6 are statistical coefficients (Figure 4.4 b). The last term is the original Zhang equation.

The proposed terms accounted for the first flush, followed by an increase commanded by the parabolic term until the runoff rate increased enough to lead to the equilibrium stage. This model improvement reduced mean absolute error from 0.9 to 0.2 and increased r^2 from 0.035 to 0.886 (Table 4.1).

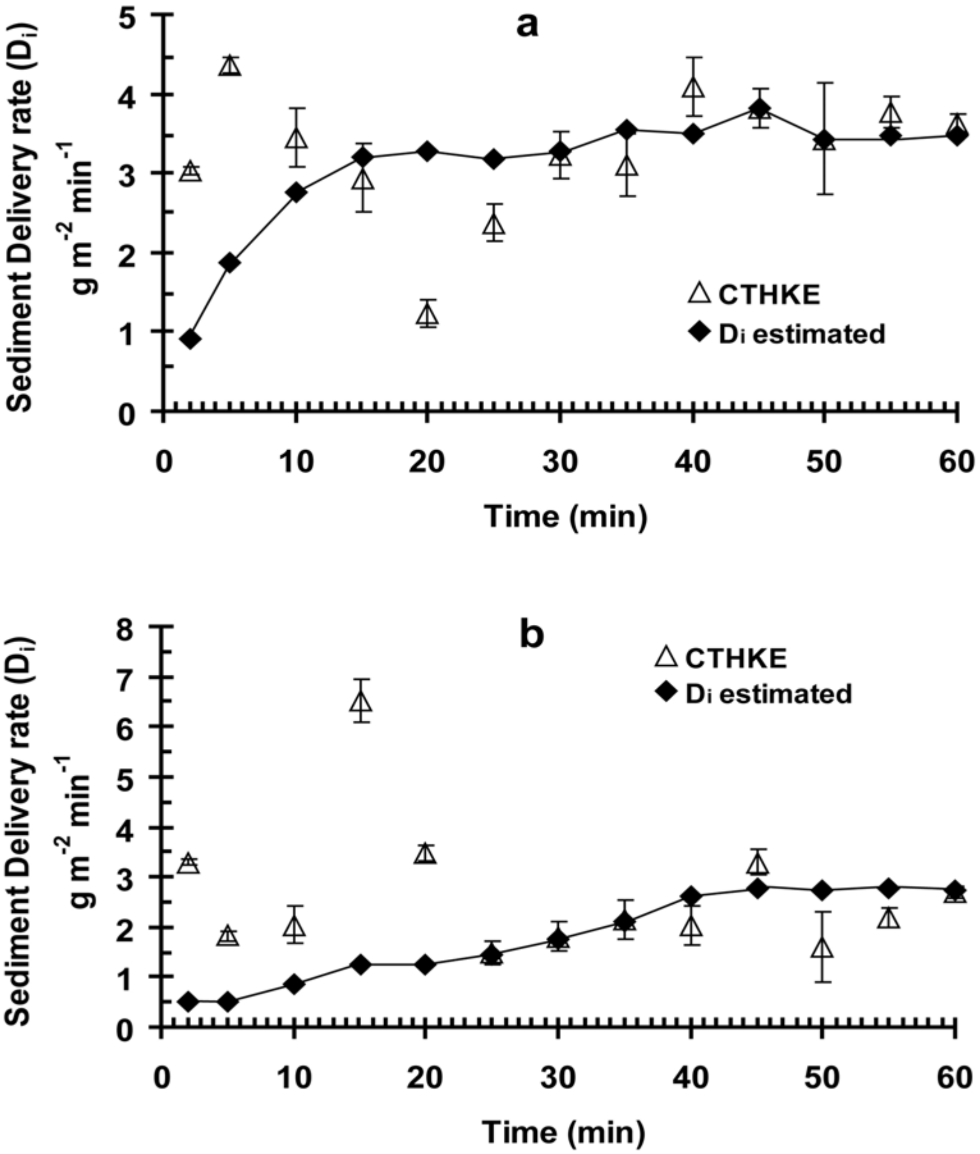


Figure 4.3: Sediment delivery rate measured and estimated by the Zhang equation (Zhang et al. 1998) in the Calloway soil (a) and in the Maury soil (b) under conventional tillage (CT) with high kinetic energy wetting (HKE).

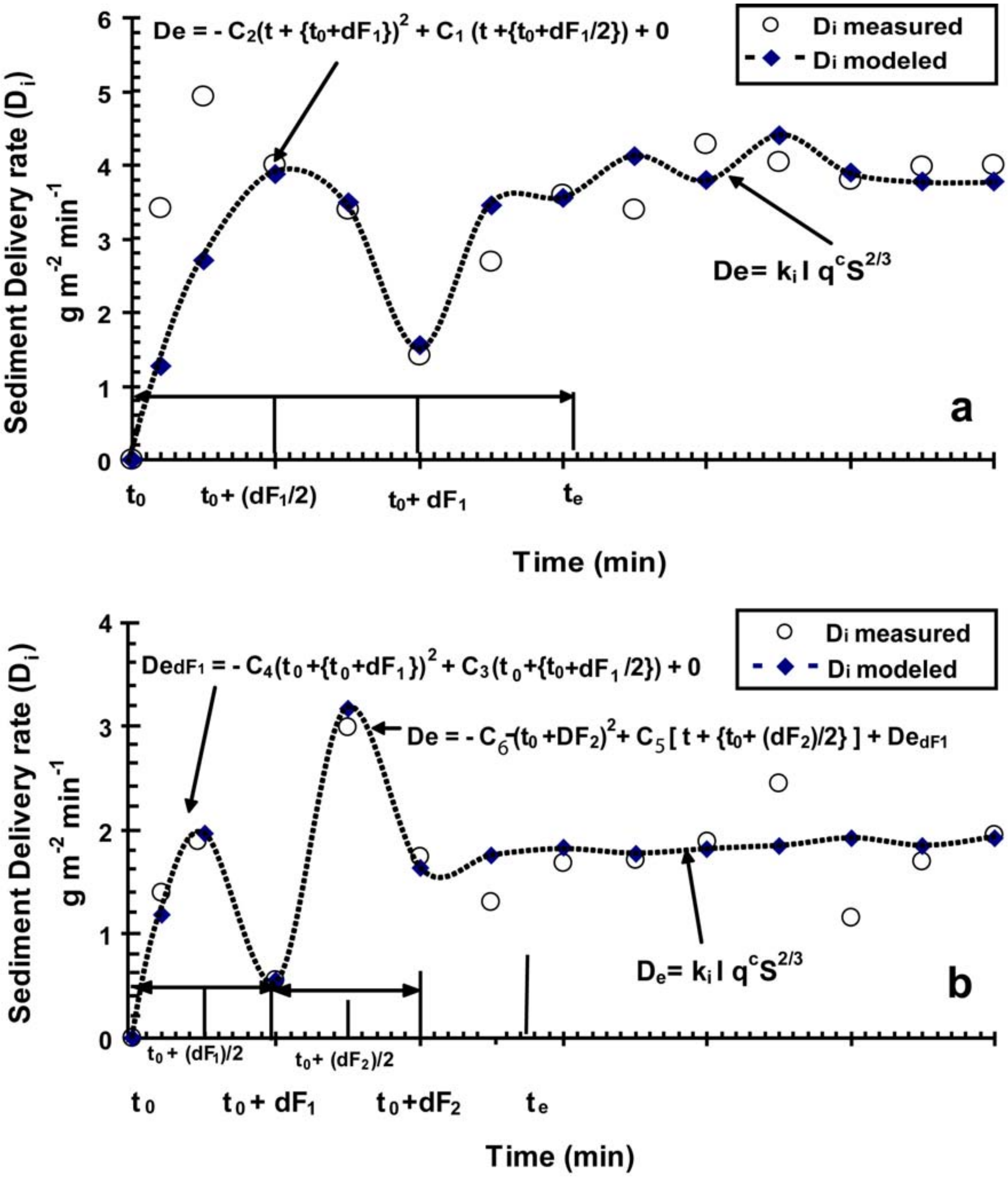


Figure 4.4: Empirical scheme to show differences with model of Zhang et al. (1998) for sediment delivery rate (Di) in the Calloway (a) and in the Maury soil (b) under conventional tillage (CT) with high kinetic energy wetting.

Table 4.1: Statistical parameters from models when compared sediment delivery rate measured in the Calloway and in the Maury soil under conventional tillage (CT) with high kinetic energy wetting (HKE), predicted with the original and a modified Zhang equation.

Parameters	Calloway soil		Maury soil	
	Zhang equation	Zhang modified	Zhang equation	Zhang modified
CC	0.3	0.8	-0.2	0.9
r square	21.0	70.5	3.5	88.6
r square (adj)	15.0	65.2	5.1	87.0
MAE	0.7	0.4	0.9	0.2

Abbreviations: CC= correlation coefficient; MAE = mean absolute error

Asadi et al. (2007b) mentioned that in some situations an overland flow with low energy (low power stream) could not remove all particle sizes. According to this study in some cases, particle size distribution became bimodal and no satisfactory explanation existed for this finding. They suggested that particles of 0.1 mm and 0.5 mm size apparently could resist the transport caused by a low runoff rate. Thus, they supposed that the mechanisms of particle transport in an overland flow, i.e., suspension, saltation and rolling, could interact to dominate the movement of different sediment size and change particle size distribution. Implicit in this assumption is that soil is a passive participant in this process.

The modified Zhang equation (equations 13 and 14) is based on the assumption that the proposed mixed mechanisms, water disintegration and turbulence in shallow overland flow, could be responsible for particle size distribution behavior in a consolidate soil, i.e., in cropland. The model was improved by introducing a way to account for the non-equilibrium stage, which assumes that soil has factors that can regulate particle size distribution.

This empirical model described two different soil behaviors when exposed to high kinetic energy wetting. One of these behaviors corresponds to a soil with natural weakness, low aggregation factors that determine a low water aggregate stability. This natural weakness could be due to high silt content. Soils of this kind tend to disintegrate completely in elementary particles, and easily develop a thick soil surface sealing. The Calloway could be included in these kinds of soils, which after an initial particle flush, reach a steady state at high level of soil loss.

The second behavior corresponds to a soil with several aggregation factors which in spite of a low water aggregate stability, do not disintegrate aggregates completely into elementary particles but also in macro and micro aggregates. Aggregation factors could be clay content, iron hydroxides and organic carbon. The Maury could be included in these kinds of soils, which show at least two particle flushes at different times before they reach a steady state condition.

4.5. Effect of wetting rate in total organic carbon, organic carbon delivery rate, enrichment ratio in organic carbon (ER_{OC}) and total carbon delivery in the sediment

Total organic carbon content in sediment produced via interrill erosion did not change in time. Data showed that TOC loss depended on interaction soil by tillage, and that wetting rate was not responsible for these losses. This finding is very important because it emphasizes that despite temporal changes in particle release, TOC concentration showed no changes. In other words, OC mobilization is a constant process during rainfall.

One reason for that finding could be the convection-dispersion process (Biggar and Nielsen, 1967) which implies that when organic carbon is released a gradient is developed that contributes to mobilizing OC from the inside to the outside of aggregates. The OC movement that occurs through the porous systems is contributing to maintain TOC loss constant during time.

It was recognized recently that a new input of OC or nutrients into the soil tends to coat the aggregates externally (Kirchhof and Daniel, 2003). This behavior should be potentially risky for the environment in soils under NT because the OC input in this system is large and continuous. However, low OC input in soils under CT surely has risk for soil sustainability, because it determines continuous soil deterioration, even though CT supports a low level of OC mobilization.

Organic carbon delivery rate (OC_{Di}) showed that OC fluxes under NT were reduced with LKE compared with HKE and it was equilibrated at values lower than 0.01 g C m^2 min^{-1}, approximately. Under CT in both soils, OC reached equilibrium at values of 0.02 g C m^2 min^{-1}. Our data of TCD showed that these delivery rates represented a C loss from 0.35 to 0.42 g C m^{-2} with HKE and from 0.02 to 0.04 g C m^{-2} with LKE in a single rainfall event.

Organic carbon exported in croplands is supposed to vary from 15.5 g C m^{-2} yr^{-1} to 3.4 g C m^{-2} yr^{-1} (Van Oost et al., 2007). Notice that according to our data, 10 events per year reached a minimum value with HKE ($0.35 \times 10 = 3.5$ g C m^{-2} yr^{-1}), but with LKE, C losses were lower than estimated ($0.02 \times 10 = 0.2$ g C m^{-2} yr^{-1}).

Because very low kinetic energy is involved in LKE treatment, only 10 events per year should be a very conservative analysis and total C loss could be underestimated.

Thus, organic carbon losses in cropland estimated by Van Oost et al. (2007) seem reasonable. However, Van Oost et al. (2007) included all kinds of water erosion processes in their analysis, while our data considered only soil erosion at a very small slope (< 1.5 %). This illustrates the importance of interrill erosion as a powerful process of OC loss, but still it is necessary to consider other large sources of OC loss like rill or gully erosion.

TCD values under NT with LKE in the Maury soil could represent a baseline to use in C budget analyses, which represented an important issue for future research. However, it is necessary to reiterate here that in this study, LKE represented almost 100 % of soil cover, very different from the 60% of soil cover recommended as a good conservation tillage practice. This should be taken into account to establish the real value of TCD under NT with different surface cover conditions.

Enrichment ratio in organic carbon in particles smaller than 0.053 mm showed that, despite temporal changes, particles take OC depending on the interaction between soil type and kinetic energy wetting. Notice that enrichment ratio remained independent on temporal variations during rainfall. Thus, it is also a constant process.

ER_{OC} values found in rainfall simulation were similar to those observed in literature, which ranged from 1.03 to 1.89 (Polyakov and Lal, 2008; Schiettecatte et al., 2008b). However, the question about how particles are enriched remains without a proper answer. Is it a simple effect of OC release in the overland flow?

If this is a simple effect, a particle takes OC during transport and simply becomes enriched. Evidence of this process can be observed in Table A in the Appendix. All particle size classes became enriched during all periods of time, but some of them had values equal or lower than one. This means that they were *sources* of OC. Principally, this situation appeared in particles in all the range from 0.105 to 0.500 mm. This means that sand size particles, microaggregates and macroaggregates were contributed with the pool of OC in the overland flow. Possibly, they also contributed to the OC enrichment process in the entire range of particles smaller than 0.105 mm. However, notice also that sometimes this situation was not observed from the beginning, thus suggesting that other sources were activated in the beginning of rainfall.

In this scenario, labile POM-C and dissolved organic carbon (DOC) should be involved because theoretically, this portion of TOC is more physically mobilized in water. DOC is the difference between TOC and POM-C and these values differ from one soil to another (Kjaergaard et al., 2004a; Haile-Mariam et al., 2008).

Labile POM-C or the light fraction is commonly referred to as a less stable fraction with high OC concentration (Golchin et al., 1995; Baldock et al., 1997) and it is considered the physically most mobile OC fraction in soils (Polyakov and Lal, 2008). Because of its low density, it could be one of the major causes of OC enrichment during erosion (Ghadiri and Rose, 1991).

Evidence that macro aggregate stability in grasslands soils decreases the POM-C release for slaking was mentioned in the literature (Gale et al., 2000b) because clay particles can easily protect OC by building aggregates (Bossuyt et al., 2002). A conceptual model was published that assumes the presence of unstable macro aggregates (0.5 mm in size) in soils, which when disrupted by slaking results in the release of POM-C into a free POM-C pool (Golchin et al., 1998). In addition, these macro aggregates have new and unstable micro aggregates (0.250 mm in size) inside of them, which also can easily release new free POM-C. Differences in stability could explain why not all macroaggregates became sources of OC in overland flow in our data (Table A4 to A8).

Thus, because our surface cover was a plastic mesh, no other source of free POM-C existed in our experiment that could explain this increase in OC. Our findings support the assumption of Ghadiri and Rose (1991), and suggested that particles smaller than 0.053 mm were absorbing OC during the transport process from the pool of free POM-C to maintain an ER_{OC} higher than 1.

On the other hand, there was no evidence that the kinetic energy was important to increase $ER_{OC.}$ This suggested that the principal process to release OC should be the slaking produced by low wetting or submergence. Shiettecatte et al. (2008b) mentioned that raindrop impact is not important as an OC enrichment mechanism, which was supported in our experiments by comparing the effect of low and high kinetic energy that produced no differences in ER_{OC}.

4.6. Effect of wetting rate on enrichment ratio in iron (ER_{Fe}) and total iron delivery in the sediment

Enrichment ratio in iron (ER_{Fe}) measured in both soils in this study confirmed that iron loss is a continuous process, as was observed with OC loss. ER_{Fe} was maintained at 1 or higher, which means that these soils continuously released iron. Patterns observed in both soils seem to confirm that aggregate rupture was involved in this process, because several peaks appeared in different periods of time.

Although iron (hydr-) oxides have been observed to stimulate aggregation, their role in soil structure is still poorly understood (Rhoton et al., 2002; Duiker et al., 2003). Crystalline Fe (hydr)oxides were mentioned as a reason for lack of correlation between soil aggregation and iron content. Poor crystalline iron hydroxides seem to be more effective than crystalline iron hydroxides in soil aggregation because they have the most reactive surface area. Particularly, it was interesting that some studies found that Fe (hydr)oxides crystalline explained differences in erodibility of loess-derived soils (Rhoton et al., 2003).

In a sandy loam soil, a relatively high concentration of Fe was found in the finest fraction of sediment, suggesting that a significant proportion of iron was presented as Fe (hydr)oxide surface coatings (Benedetti et al., 2003). Soil organic compounds can increase the ability of iron to improve soil aggregation. However, formation of organic-inner- sphere complexes on Fe (hydr) oxides surfaces and bridges with silt-clay particles also can mobilize iron with the sediment into overland flow.

Humic substances and Fe interact to form complexes, that allow Fe to remain in solution under conditions under which it would otherwise, precipitate (Maloney et al., 2005). In these complexes, Fe could be transported for long distances in runoff water. In our study, it was found that iron release seemed to be independent of wetting rate. With exception of treatments under CT with HKE, all the other combinations showed ER_{Fe} values close to or higher than 1, which means that these soils were very susceptible to loosing iron.

Total iron delivery (TID), measured in particles smaller than 0.053 mm in the Calloway soil under CT with HKE ranged from 0.2 to 0.25 mg Fe m^{-2}. This represented a loss from 20 to 25 g Fe ha^{-1} by considering a single event. Under NT with LKE this loss ranged from 0.03 to 0.07 mg Fe m^{-2}, which means 0.3 g Fe ha^{-1}. In the Maury soil under CT with HKE, TID values were higher than in the Calloway soil (0.48 mg Fe m^{-2}). Under NT with LKE values were similar to the values observed in the Calloway soil. In other words, shallow overland flow with very low energy can mobilize a large amount of iron from these soils.

Rhoton et al. (2003) analyzed different watersheds with sandy and sandy loam soils, and found values of ER_{Fe} from 3.5 to 1.89. Notice that extreme values of ER_{Fe} were also observed in Figure 3.19 in the Calloway soil under CT with HKE. However, no clear explanation exists for this behavior. If aggregate rupture was involved, these extreme values would occur when particle flush appeared, but these extreme values were not related with particles smaller than 0.053. The extreme values were related with particles in the range from 0.250 to 0.500 and from 0.500 to 1.000 mm. Possibly, iron was involved by bonding these particles together, i.e., when these bonds were broken the iron released was immediately sequestered by silt-clay particles size, thus producing the extreme values of ER_{Fe}.

Section 5. CONCLUSIONS

This study analyzed the wetting behavior of soil aggregates from conventional tillage compared with no tillage, under the assumption that the wetting rate is a function of the porous system and that different tillage systems could modify the soil parameters and pore stability, thus affecting soil wetting. The second objective was to analyze relationships among soil wetting, particle movement, organic carbon and iron release with the sediment produced via interrill erosion.

Conventional tillage systems as defined in this study are aggressive and increased problems associated with non point source pollution due to the amount of particles released. This tillage system determined a reduction in TOC, GMD and MWD in both soils in this study, especially in the Calloway silt soil. The importance of this reduction should be interpreted as an example of soil degradation that conventional tillage practices caused in these soils proving that this tillage system was not sustainable. On the contrary, evidence observed in our data showed that NT could conserve these soil parameters, which maintained the soil functions principally associated to water movement and erodibility.

Analysis at the aggregate scale reflected heterogeneity in soil parameters and how these parameters vary from one situation to another when soil was exposed to tillage systems. The most modified soil parameters were TOC and POM-C. At this scale, this study showed how aggregate properties were conserved under NT and also how aggregates of different sizes have independent behavior when exposed to water. Thus, particle release is different depending on specific aggregate size. This was strong evidence that stability should be improved at all aggregate levels to control particle release.

One of the most important findings in this study was observed by comparing various chemical and biological soil parameters with wetting rate and water uptake. In spite of what was expected, no direct relationships were found for soil chemical and biological parameters neither with wetting rate nor with water content.

New evidence found in literature about the effect of OC and iron deposition on particle surface and how this deposition could affect soil wetting indicate a need to improve our methodology to determine underlying processes. This could be accomplished by creating micro methods and sampling methodology appropriate for the aggregate scale. Understanding the relationship between OC deposits and interaction with cations to built new aggregates should be very useful. In this aspect, scanning electron microscope images should be illustrative and represent opportunities to improve our knowledge about aggregation. This information should be integrated with experiments of amendments (OC and poorly crystalline Fe) to explore the effect on wetting rate and to test aggregate breakdown.

A need exists to know how to control aggregate ruptures and how to stabilize porous systems. Amendments with OC and poorly crystalline iron could be useful to increase soil stability. Also, it would be necessary to determine if a limited water aggregate resistance exists and if there is a boundary imposed by soil texture or by OC balance.

As was found in this study, the resistance to slaking and friability developed in the Maury soil under NT compared with behavior under CT, showed a potential way to control soil stability.

Soil characteristics and different kinetic energy wetting were more important than tillage in releasing particles when exposed to rainfall. A trend to lose silt-clay size particles during rainfall was observed in soil even in a low kinetic energy wetting stage, which should be controlled. It is an important finding that release of particles smaller than 0.053 mm was not a function of clay content but a result of combined effects among soil, tillage, energy and time because this means that particle release could be controlled with soil management.

Data showed that observed particles flush during rainfall depending of the aggregation factors, and this study showed that this occurred with any particle size. The idea that temporal water submergence is responsible for particles flush when a threshold is overcome is relevant to improve current physical erosion models. A significant finding was to show that particle release could be controlled through both surface cover and aggregate stability, because friability and slaking processes act together during interrill erosion.

The modification proposed for the prediction equation is reliable because it assumes that soil is not a passive subject in the erosive process. On the contrary, it is a determinant. According with this idea, the soils under study represented two different behaviors when exposed to rainfall, which could be related with soil properties and submergence time. Soil parameters can be improved to reduce soil erosion until values still unknown, especially in terms of sediment quality.

Another important finding of this study was that OC release from soil is a constant process. This means that different and very active sources exist during an entire rainfall, which represents an enormous risk for soil degradation. The principal vehicle identified were particles smaller than 0.053 mm, which are continuously released from soil surfaces and should be controlled. It is necessary to know the limits of this release, especially because under surface cover, particles still remain in movement. Colloid control should be a priority to improve non point source of pollution that depends on erosive processes.

Iron release observed in these soils emphasizes an aspect not often analyzed in soil erosion literature, but that is more addressed to explore OC issues. However, iron release could represent a new and very important field of study. There is an enormous uncertainty about the role of OC in the release of iron, what kind of iron species are more easily released with OC or why particles smaller of 0.053 mm are the vehicle. If this is a simple effect of OC-Fe relationships, are particles involved iron hydroxides themselves or both? On the contrary, the possibility to use iron to improve aggregate stability in combination with OC sources should be explored. This seems to be a promising management practice to investigate in order to accelerate recovery of soil stability under no tillage.

APPENDIX

Table A1: Total organic carbon (g kg^{-1}) in the particles released by interril erosion in the Calloway soil under no tillage (NT).

TIME	Range of particles (mm)									
	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	18.7a	26.5b	19.8a	15.7b	29.8a	31.0a	30.3a	20.4b	25.9a	25.7a
5	15.0a	22.6b	16.1a	15.9a	26.5a	29.3a	32.0a	18.5b	25.2a	24.3a
10	22.3a	20.6b	15.3a	17.2a	27.2a	32.0b	32.1a	20.3b	23.9a	25.5b
15	15.5a	23.7b	14.9a	15.4a	23.3a	29.6b	28.0a	19.9b	20.0a	27.4b
20	15.5a	24.2b	21.6a	17.2b	20.4a	29.2b	30.3a	20.2b	24.0a	24.2a
25	20.9a	23.1b	21.8a	16.1b	15.6a	21.4b	26.3a	20.4b	27.3a	23.9b
30	23.5a	25.2b	19.0a	15.5b	17.1a	20.6b	23.6a	21.6b	28.8a	26.4b
35	21.2a	23.9b	18.4a	15.2b	19.6a	18.8a	28.7a	21.7b	27.9a	26.0b
40	18.7a	22.4b	21.0a	15.2b	18.7a	26.0b	26.5a	20.2b	27.6a	20.8b
45	18.7a	23.4b	13.2a	13.0a	17.2a	21.2b	26.6a	17.2b	28.1a	21.7b
50	27.0a	23.3b	16.2a	14.5b	16.3a	18.7b	26.0a	13.9b	28.0a	26.8b
55	29.8a	21.5b	22.8a	13.7b	19.9a	24.0b	27.3a	18.7b	25.1a	23.3b
60	21.3a	23.9b	22.5a	15.8b	22.4a	26.6b	27.3a	17.2b	27.3a	26.0b

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A2: Total organic carbon (g kg^{-1}) in the particles released by interril erosion in the Calloway soil under CT

TIME	Range of particles (mm)									
	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	9.6a	9.6a	19.2a	17.5b	26.1a	16.5b	19.7a	14.3b	33.4a	26.4b
5	8.5a	9.2a	21.2a	19.1a	23.3a	14.6b	18.0a	13.9b	28.4a	22.5b
10	7.9a	9.3b	20.0a	18.0b	23.9a	12.1b	19.6a	13.6b	29.4a	25.3b
15	8.1a	11.8b	18.2a	17.4a	22.0a	14.1b	18.5a	13.6b	27.5a	24.5b
20	8.8a	11.2b	17.6a	18.7a	21.4a	16.6b	22.9a	13.2b	29.2a	31.7a
25	8.8a	13.1b	18.6a	16.5b	24.2a	18.2b	26.7a	13.0b	28.3a	27.7a
30	8.5a	16.1b	25.9a	17.4b	31.9a	16.7b	25.9a	13.6b	28.1a	27.7a
35	8.3a	13.6b	16.3a	18.7b	23.2a	13.5b	26.1a	13.4b	27.5a	32.0b
40	8.0a	14.1b	20.5a	19.6a	22.3a	14.8b	25.3a	13.4b	21.2a	26.4b
45	8.2a	13.8b	18.7a	18.7a	22.9a	17.0b	22.9a	13.4b	21.6a	25.2b
50	7.9a	11.8b	17.5a	19.9b	25.2a	17.7b	18.0a	13.6b	20.7a	25.0b
55	7.5a	12.5b	19.1a	18.2a	23.2a	16.2b	12.5a	13.0a	20.8a	24.0b
60	7.5a	9.5b	20.1a	18.5b	22.4a	15.8b	18.8a	15.4b	19.0a	16.7b

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A3: Total organic carbon (g kg^{-1}) in the particles released by interril erosion in the Maury soil under NT

	Range of particles (mm)									
TIME	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	26.2a	32.3b	23.3a	22.5a	28.4a	23.4b	30.6a	30.6a	29.8a	23.4b
5	27.4a	32.6b	22.7a	26.9b	24.9a	27.1b	28.4a	29.8a	26.0a	23.6b
10	25.2a	30.7b	20.9a	23.0b	26.4a	30.3b	26.5a	29.9b	24.8a	25.9a
15	23.2a	22.1a	16.5a	24.5b	28.7a	20.9b	24.6a	31.8b	19.1a	25.7b
20	21.8a	28.6b	20.1a	31.7b	27.1a	22.8b	25.1a	32.5b	24.4a	24.3a
25	28.5a	32.6b	21.2a	27.7b	25.0a	25.1a	27.5a	32.0b	28.6a	23.1b
30	29.8a	28.1a	20.3a	27.7b	29.7a	24.9b	32.5a	30.6b	25.9a	27.4b
35	22.4a	22.4a	23.2a	32.0b	26.4a	23.6b	34.0a	26.8b	29.4a	23.6b
40	24.7a	25.8a	16.8a	26.4b	31.3a	25.5b	29.6a	29.2a	30.7a	22.6b
45	28.6a	29.3a	22.2a	25.2b	33.2a	25.4b	32.8a	28.7b	29.9a	24.7b
50	27.4a	26.2a	22.2a	28.1b	27.1a	25.3b	29.2a	28.2a	29.2a	26.6b
55	26.6a	27.4a	24.6a	23.7a	21.9a	25.5b	28.4a	28.7a	28.4a	28.1a
60	24.9a	27.1b	22.9a	21.4a	25.0a	26.6a	32.6a	26.5b	27.4a	27.8a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A4: Total organic carbon (g kg^{-1}) in the particles released by interril erosion in the Maury soil under CT

TIME	Range of particles (mm)									
	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	19.7a	20.0a	25.5a	26.4a	13.4a	18.2b	17.8a	13.6b	29.8a	24.5b
5	20.8a	15.8b	25.9a	26.5a	12.5a	16.5b	17.3a	18.4a	25.6a	26.5a
10	22.1a	18.2b	27.5a	21.1b	13.6a	17.5b	14.2a	15.0a	23.4a	23.6a
15	23.0a	18.6b	25.7a	20.9b	13.4a	17.5b	13.2a	14.4a	21.1a	27.2b
20	19.9a	20.4a	27.3a	24.4b	12.7a	19.0b	14.4a	16.0b	21.0a	21.5a
25	18.0a	19.2a	30.0a	25.0b	12.7a	18.1b	12.0a	15.5b	23.7a	27.9b
30	20.7a	18.0b	26.1a	27.5a	13.6a	18.3b	12.8a	15.5b	23.8a	24.5a
35	21.1a	18.7b	17.0a	23.2b	14.0a	24.6b	13.0a	16.2b	23.5a	26.4b
40	20.7a	16.7b	23.0a	21.0a	13.8a	23.3b	13.8a	16.6b	20.2a	25.9b
45	21.4a	18.5b	33.8a	24.2b	12.7a	22.3b	13.2a	15.8b	17.5a	28.6b
50	20.3a	14.8b	21.2a	25.7b	12.9a	22.1b	13.3a	15.9b	17.1a	19.3b
55	20.4a	17.9b	22.3a	27.3b	16.5a	21.0b	11.9a	14.5b	14.5a	28.2b
60	19.3a	16.5b	24.7a	23.2b	16.1a	20.6b	12.7a	15.9b	17.5a	18.6a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A5: Enrichment ratio in organic carbon (ER_{OC}) measured in the sediment produced by interrill erosion in the Calloway soil under NT

TIME	Range of particles (mm)									
	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	2.7a	3.9b	1.5a	1.2a	1.4a	1.4a	1.5a	1.0b	1.5a	1.5a
5	2.2a	3.3b	1.2a	1.2a	1.2a	1.4a	1.6a	0.9b	1.4a	1.4a
10	3.3a	3.0a	1.1a	1.3a	1.3a	1.5a	1.6a	1.0b	1.4a	1.5a
15	2.3a	3.5b	1.1a	1.2a	1.1a	1.4b	1.4a	1.0b	1.1a	1.6b
20	2.3a	3.6b	1.6a	1.3b	0.9a	1.3b	1.5a	1.0b	1.4a	1.4a
25	3.1a	3.4a	1.6a	1.2b	0.7a	1.0b	1.3a	1.0b	1.5a	1.4a
30	3.5a	3.7a	1.4a	1.2a	0.8a	0.9a	1.2a	1.1b	1.6a	1.5a
35	3.1a	3.5a	1.4a	1.1a	0.9a	0.9a	1.4a	1.1b	1.6a	1.5a
40	2.8a	3.3a	1.6a	1.1b	0.9a	1.2b	1.3a	1.0b	1.6a	1.2b
45	2.7a	3.4b	1.0a	1.0a	0.8a	1.0a	1.3a	0.8b	1.6a	1.2b
50	4.0a	3.4a	1.2a	1.1a	0.8a	0.9a	1.3a	0.7b	1.6a	1.5a
55	4.4a	3.2a	1.7a	1.0b	0.9a	1.1a	1.3a	0.9b	1.4a	1.3a
60	3.1a	3.5b	1.7a	1.2b	1.0a	1.2a	1.3a	0.8b	1.6a	1.5a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A6: Enrichment ratio in organic carbon (ER_{OC}) measured in the sediment produced by interrill erosion in the Calloway soil under CT

	Range of particles (mm)									
TIME	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	1.8a	1.8a	2.0a	1.8a	2.0a	1.2b	1.7a	1.2b	2.3a	1.8b
5	1.6a	1.7a	2.2a	1.9b	1.8a	1.1b	1.6a	1.2b	2.0a	1.6b
10	1.5a	1.7a	2.0a	1.8a	1.8a	0.9b	1.7a	1.2b	2.1a	1.8b
15	1.5a	2.2b	1.9a	1.8a	1.7a	1.1b	1.6a	1.2b	1.9a	1.7a
20	1.7a	2.1b	1.8a	1.9a	1.6a	1.2b	2.0a	1.1b	2.0a	2.2a
25	1.7a	2.5b	1.9a	1.7a	1.8a	1.4b	2.3a	1.1b	2.0a	1.9a
30	1.6a	3.0b	2.6a	1.8b	2.4a	1.3b	2.2a	1.2b	2.0a	1.9a
35	1.6a	2.6b	1.7a	1.9a	1.7a	1.0b	2.2a	1.2b	1.9a	2.2b
40	1.5a	2.7b	2.1a	2.0a	1.7a	1.1b	2.2a	1.2b	1.5a	1.8b
45	1.5a	2.6b	1.9a	1.9a	1.7a	1.3b	2.0a	1.2b	1.5a	1.8b
50	1.5a	2.2b	1.8a	2.0a	1.9a	1.3b	1.6a	1.2b	1.4a	1.7b
55	1.4a	2.4b	1.9a	1.9a	1.7a	1.2b	1.1a	1.1a	1.5a	1.7b
60	1.4a	1.8b	2.1a	1.9a	1.7a	1.2b	1.6a	1.3b	1.3a	1.2a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A7: Enrichment ratio in organic carbon (ER_{OC}) measured in the sediment produced by interrill erosion in the Maury soil under NT

	Range of particles (mm)									
TIME	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	1.6a	1.9b	0.7a	0.6a	0.9a	0.7a	1.0a	1.0a	1.1a	0.9a
5	1.6a	1.9b	0.6a	0.8a	0.8a	0.8a	0.9a	1.0a	1.0a	0.9a
10	1.5a	1.8b	0.6a	0.7a	0.8a	0.9a	0.9a	1.0a	0.9a	1.0a
15	1.4a	1.3a	0.5a	0.7a	0.9a	0.6b	0.8a	1.1b	0.7a	0.9a
20	1.3a	1.7b	0.6a	0.9b	0.8a	0.7a	0.8a	1.1b	0.9a	0.9a
25	1.7a	1.9b	0.6a	0.8a	0.8a	0.8a	0.9a	1.1a	1.1a	0.9a
30	1.8a	1.7a	0.6a	0.8a	0.9a	0.8a	1.1a	1.0a	1.0a	1.0a
35	1.3a	1.3a	0.7a	0.9a	0.8a	0.7a	1.1a	0.9a	1.1a	0.9a
40	1.5a	1.5a	0.5a	0.8b	1.0a	0.8a	1.0a	1.0a	1.1a	0.8a
45	1.7a	1.7a	0.6a	0.7a	1.0a	0.8a	1.1a	0.9a	1.1a	0.9a
50	1.6a	1.6a	0.6a	0.8a	0.8a	0.8a	1.0a	0.9a	1.1a	1.0a
55	1.6a	1.6a	0.7a	0.7a	0.7a	0.8a	0.9a	0.9a	1.0a	1.0a
60	1.5a	1.6a	0.7a	0.6a	0.8a	0.8a	1.1a	0.9a	1.0a	1.0a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

Table A8: Enrichment ratio in organic carbon (ER_{OC}) measured in the sediment produced by interrill erosion in the Maury soil under CT

TIME	Range of particles (mm)									
	< 0.053		0.053 -0.105		0.105 -0.250		0.250 -0.500		0.500 -1.000	
	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE	HKE	LKE
2	1.7a	1.8a	1.3a	1.3a	0.8a	1.1b	1.0a	0.8b	2.1a	1.7b
5	1.8a	1.4b	1.3a	1.3a	0.7a	1.0b	1.0a	1.1a	1.8a	1.9a
10	1.9a	1.6b	1.4a	1.0b	0.8a	1.0a	0.8a	0.9a	1.6a	1.6a
15	2.0a	1.6b	1.3a	1.0b	0.8a	1.0a	0.8a	0.8a	1.5a	1.9b
20	1.7a	1.8a	1.4a	1.2a	0.7a	1.1b	0.8a	0.9a	1.5a	1.5a
25	1.6a	1.7a	1.5a	1.2b	0.7a	1.1b	0.7a	0.9a	1.7a	2.0b
30	1.8a	1.6a	1.3a	1.4a	0.8a	1.1b	0.7a	0.9a	1.7a	1.7a
35	1.9a	1.6b	0.8a	1.2b	0.8a	1.4b	0.8a	0.9a	1.6a	1.8a
40	1.8a	1.5b	1.1a	1.0a	0.8a	1.4b	0.8a	1.0b	1.4a	1.8b
45	1.9a	1.6b	1.7a	1.2b	0.7a	1.3b	0.8a	0.9a	1.2a	2.0b
50	1.8a	1.3b	1.1a	1.3a	0.8a	1.3b	0.8a	0.9a	1.2a	1.3a
55	1.8a	1.6a	1.1a	1.4b	1.0a	1.2a	0.7a	0.8a	1.0a	2.0b
60	1.7a	1.4b	1.2a	1.2a	0.9a	1.2a	0.7a	0.9a	1.2a	1.3a

Abbreviatons: HKE= high kinetic energy wetting; LKE= low kinetic energy wetting. Letter in the same row for each range of particles means significant at $p < 0.05$.

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[1] “ The true sign of intelligence is not knowledge but imagination”. Albert Einstein