

Quality of soil organic matter under different management practices in a tropical acid soil

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Abstract

Dynamic of soil organic matter (SOM) in tropical savannahs is of growing interest because of the recent rapid increase of cultivation and the questions concerning their sustainability under intensive land use. As most of the soils of Venezuela are highly weathered and nutrient poor, the significance of SOM for soil fertility is even greater than temperate soils. A continuous sorghum study was initiated in 1999, located in Espino, Guárico state, Venezuela. It included fresh residues incorporation (grass, legumes, and native sod) with minimum tillage. No residue treatment and fallow were used as control. Organic C, mineralizable C, and C coming from microbial biomass were determined in soil samples collected at 10 cm depth during 2002. Subsamples also were separated into four aggregates size classes by wet sieving. Soil N mineralization was determined *in situ* in the field, during 2001. Soil organic C was divided into microbial, mineralizable, and resistant fractions. Cultivation decreased microbial biomass by 50%, and stable C by approximately 9%, but increased non-biomass C by 40% compared to fallow. Management practices did not affect significantly microaggregates proportion, but legumes and native sod residues increased macroaggregates amount. Net N mineralization was significantly increased by 40% by native sod residues compared to fallow. Incorporation of legumes residues increased carbon mineralization, and stimulated microbial activity. The ratio of microbial activity to soil microbial carbon was higher under legumes than under the other systems, indicating that microbes under legumes treatment have been most active. The results indicate that legumes residues with minimum tillage contribute to increase macroaggregates, and weaknesse fractions of C in highly weathered tropical soils.

Key words: organic matter fractions, aggregates, N and C mineralization.

Introduction

The interest in the study of the dynamics of soil organic matter (SOM) in tropical in Venezuelan savannas has increased in the last years due to the fast rise of the agricultural operation, in addition to the search of responses to questions related to the land sustainability under intensive agricultural use. (Hernández and López, 2002). The change of use of natural savannah land to culture greatly affects the structural ability and diminishes the organic land amount of C (van Veen and Paul, 1981), this loss of C reduces the proportion of macroaggregates of soil (Elliot, 1986; Gupta and Germida, 1988; Cambardella and Elliot, 1993; Freibauer *et al.*, 1999) since they are mostly affected by the handling practices. The tillage breaks the aggregates soil and releases the particulate organic matters (Six *et al.*, 1998) which increases the contact of residues with the microorganisms (Reicosky and Lindstrom, 1995). This is a consequence which brings an increase of oxidation of these residues that were protected within the aggregates (Beare *et al.*, 1994), reason why it is possible to conclude that the aggregation and content of SOM depend on the use of land and the cultivar systems. The conservationists handling systems, such as mini tillage and green fertilizer, have been proposed as alternative systems of handling to reduce lost of soil by erosion (Taylor *et al.*, 1964), improvement of the efficiency in the use of water (Smika

and Unger, 1986) and increase the concentration of C of the superficial soil (Karlen *et al.*, 1994). The conservationist soil handling has been suggested as a method to transform all the soil system of atmospheric source of C made a drain net of C (Kern and Johnson, 1993). The amount of SOM is a function of the amount of residues of plants that enter in the soil and the rates of decomposition of those residues. In addition to the climate, the type and quality of substrate (contained of N, relation C:N and lignin: N) are important factors that regulate the processes of decomposition of the SOM (Jastrow and Miller, 1997). The stabilization of the SOM can increase with the humification degree, by the association with the mineral phase and by the protection of the SOM within aggregates. This last stabilization is due to the SOM is kept in small pores of aggregates, so that the microorganisms cannot have access to the substrate (Elliot and Coleman, 1988). The paper of the protection of the SOM of the decomposition on the part of the soil structure has been demonstrated by the increase in the mineralization of the aggregate C disintegrated in relation to intact aggregates (Elliot, 1986; Gupta and Germida, 1988; Gregorich *et al.*; 1989; Beare *et al.*, 1994). The soil organic matter is a complex mixture of heterogeneous fractions with rates of different recharge parts. The characterization of the dynamics of the SOM has been

used in simulation models that include discreet fractions of C with different rates from rechange (van Veen and Paul, 1981; Parton *et al*, 1989). Many models divide the SOM in active, slow and passive fractions. The most active fraction, representing the microbial matter and soluble organic matter, constitutes 3-5 % of total the organic matter (Rice and Garcia, 1994). The slow fraction has time of residence of 10 to 50 years and represents of 20-40 % of the total C of the soil (Elliot, 1986). Both fractions

of active and slow C are considered through the measurement of microbial matter and kinetic analyses of mineralization in the laboratory (van Veen and Paul, 1981). The passive fraction with times of rechange on the order of 100 to 1000 years can be considered by difference. In this study, it was tried to determine the effect of application of vegetal wastes with mini tillage on the fractions of the organic matter, rates of mineralization of nitrogen and soil aggregation.

Materials and methods

Description of studied place

The experimental place was located in a savannah of the northeastern region of the Guárico state, near of Espino locality, Venezuela. The climate is characterized by an annual average temperature of 27 °C and a precipitation of 1136 mm. The soil has a sandy texture and has been classified like Typic Paleustults with 6, 9 and 85 % of clay, the slime and sand, respectively. With a content of total C and 1.2 N of 10 and Mg is⁻¹, respectively.

The natural vegetation this represented by ciperaceae, typical gramineae of the zone (*Trachypogon sp*, *Axonopus sp*) and the leguminous (*Indigosfera lespediade*). A field study was made to evaluate the effect of the application of green residues, gramineae (G) (sorghum), leguminous (L) (indigo) and wild vegetation (WV), in sowing of continuous sorghum. In 1999 a seedtime was conducted and

incorporation of the residues and in 2000 year was applied the basic fertilization of N, P and K and seeded the culture. The treatments controls were without residues (WR) and fallow (F). The parcels were of 2.025 m² with a distance between row of sowing of 0.45 m.s the mini tillage applied in the treatments where were applied the residues, it was a plough to the depth of 10 cm made with a rotocultor. The treatments were fixed in a design of blocks completely randomized with four replications using sorghum in dry land system. The sorghum [*Sorghum bicolor* (L.) Moench] used, Chaguarama VII, is a hybrid with abilities to adapt to acid soils.

Sampling Procedure

In 2001, before seedtime and from the application of fertilizers, ten soils random samples of 0-10 cm of depth, were obtained in each one of the parcels having used Oakfield large drills (2.26 cm of diameter). The

samples were placed in plastic of polypropylene and transported into bags to the laboratory to 4 10 approximate temperatures of 10 °C and then conserved to 4 °C until the accomplishment of the physical, chemical and microbiological analyses.

Determination of total C and N

The soil samples, taken before sowing, were dried airily through a mesh sieve of 0.15 cm, to determine the organic C by the method of humid oxidation with $K_2Cr_2O_7$ (Anderson and Ingram, 1993) and the total N following the method of Kjeldahl (Anderson and Ingram, 1993).

Analysis of microbial matter

The microbial matter of C (MMC) was determined by the fumigation-incubation technique (Jenkinson and Powlson, 1976). The soil used for the estimation of MMC was stored to 4 °C by a nongreater lapse of two weeks before the analysis. The samples were sifted through a 6-mm mesh. The soil (5 g) was added to serum bottles of 160 milliliter. When the water content was smaller of 0.28 g g⁻¹ (approx -150 kPa), water was added to it to reach that humidity content. All the samples were preincubated to 25 °C by 5 days, and then, half were fumigated with free ethanol chloroform by 18-24 h. Each fumigated soil sample received the conventional inoculate (0,5 g) of the corresponding not-fumigated soil. The fumigated and non fumigated samples were not sealed and incubated by 10 d 25 °C. At the end of the period of incubation, the concentration of CO²-C was moderate,

using a gas chromatograph Agilent 6890 (Agilent Technologies, Wilmington, DE) equipped with a column Porapak Q of 2 ms. The MMC were calculated with formulates $MMC = Fc / Kn$ where Fc = produced [CO² of fumigated soil-CO² produced of the non fumigated soil] and Kn = 0.45 (the produced microbial proportion of C like CO²).

Mineralization of carbon

Ten grams of soil was added into serum bottles of 160 milliliter. Before the analysis the samples were sifted through a 6-mm mesh. The water potential of the soil was taken to 30–J kg⁻¹ (0.30 kg water kg⁻¹ soil) with distilled water approximately. The soil was incubated to 30 °C by 65 days and the CO²-C determined as of the second day of incubation using a gas chromatograph. The potential of the mineralized C was considered of the rate of CO²- C production during 7 to 65 days of incubation, assuming that during this period the soil had reached a stable level, where most of the CO²-C flow came from the basal breathing occurred in this time. The mineralized potential C was calculated using the CO²-C produced, which is fixed to a model of kinetic of first order (Stanford and Smith, 1972) using a curve not to linear fixed to procedure PROC NLIN (SAS Institute Inc., 2000).

Physical division of soil

The fractions of aggregates were separated by soaking of the dry soil to the air, followed by sifting in humid (Elliott, 1986) through a series of four sieves (2000 :m (big macroaggregates), 250 :m (small macroaggregates), 53 :m

(great microaggregates), and 20 :m (small microaggregates). For each of the treatments, a subsample (equivalent to 100 g of dry soil to the air) was placed in the top of a sieve 2000 :m, then was submerged by 5 min in deionized water to room temperature. The separation was accompanied by a vertical movement by 3 cm, made the sieve. This manual movement, was made 50 times during a period of 2 min. The material surplus on the sieve was washed within a package of square aluminum dried to 50 °C all the night and then weighted. The soil suspension successively was sifted to the next size of sieve (Cambardella and Elliott, 1993).

Aggregate correction by sand

The dried fractions of soil in the furnace were cooled in a dryer and then dispersed in a solution of hexametaphosphate of sodium to 0.5%, by orbital agitation. The dispersed fraction was passed through sieves of 2000, 250, 53 and 20 :m, depending as large as evaluated fraction. The fraction surplus on the sieve was dried (60 °C) and heaved. The results are reported like the percentage of stability of aggregates.

Mineralization of N in the field

The mineralization of N was measured using polyvinyl chloride tubes (PCT) (diameter 10 cm, and depth 10 cm, with spiral covers, installed in the field after seedtime and placed during all the culture time 2002 year. The placing of tubes was made on the residues in the surface

of the soil. Throughout the tubes one was opened to them to holes of approximately 0.5 cm to a distance of 4 cm each. Then, approximately 2 cm over the surface were buried into the soil. Once installed the around was clean to eliminate the vegetation still on. Soil samples, using an Oakfield large drill (diameter 2.26-cm), were taken monthly during the time of growth of the culture of 2001 year. The samples were taken to 10 cm of depth within the mineralization tubes and immediately they were placed within polyethylene bags, transported to the laboratory and stored to 4 °C. Before the analysis, the samples was sifted using a size of 6-mm mesh. The water content was determined gravimetrically in sub-samples dried by 24 h 105 °C. The inorganic N was extracted to 3 g of a subsample to adding 30 milliliter of KCl 2M. The samples were shaken by 1 h with an orbital agitator to 300 RPM. The suspension was filtered through a paper Whatman filter #2 and NH₄-N and NO₃-N certain colorimetrically in an autoanalyzer Perkin Elmer, Fias 300, Ueberlingen, Germany.

Statistical Analysis

The data of every year were analyzed separately through of the SAS (SAS Institute, 2000). Proc Mixed was used like procedure for the variance analysis. For separation of difference between averages the test of minimum significant difference was used (MSD). All the results were considered significantly different from P<0,05 unless the opposite is mentioned.

Results and discussion

Chemical parameters

The organic C to 0-10 cm of depth showed small differences between the treatments and was included between 9.3 and 10.1 Mg ha⁻¹ (table 1). The highest value was observed under fallow and lowest on leguminous residues. In opposition to the observed with the organic C, total nitrogen showed significant differences between fallow and the treatment without residues. Non significant difference was observed between the treatments where B was maintained and the G, L and BV were incorporated (table 1). The found values of C and N in this study were approximately 50% lower than reported by Hernandez and Lopez (2002), in savannahs of the same region in Venezuela, but under different cropping systems. Relation C:N of the different treatments was inversely proportional to the amount of N of the soil (table 1), the C:N was smaller in the soil under fallow and the treatment where L was used, perhaps and but high recharge of C due to the availability of necessary N for the microbial decomposition (Gregorich *et al.*, 1994.) suggests affects the leguminous residues.

Microbial matter of carbon

The microbial matter of carbon (MMC) followed the same pattern of the organic C. The MMC were affected significantly by the tillage and the application of residues. An average of the measures of the treatment where the tillage was applied indicates a diminution the carbon of the microbial

matter in 64% (table 2). Respect to the application of residues, the MMC reached significant ($P < 0,1$) high (> 60 kg ha⁻¹) compared with the treatments MR. and G (35 and 44 kg ha⁻¹). It was not observed significant differences between the MMC of the treatments where it was added L and the treatment where it was added NV. An increase of the organic C, due to the microbial matter, has been suggested as an indicator of the increase of the organic matter of the soil (Polwson *et al.*, 1987). The results indicate that the MMC were affected rapidly by the culture systems, this suggests that MMC can serve as an indicator of soil changes SOM highly degraded.

Mineralization of Carbon

It is shown in figure 1 the effect of the treatments on the potential mineralization of C. The values of mineralized C (potential microbial activity) were affected significantly as much by the tillage, as by the application of residues. In the treatment where it was not applied residues the value under microbial activity was mostly observed. The loosening of CO₂ during the incubation period was greater ($P > 0,05$) in the treatments where L and NV were applied; nevertheless, this difference just observed significant difference ($P < 0,05$) with the treatment WM., where 30% than C mineralized as of day 25 were observed less of incubation compared with the rest of the treatments. This difference increased in the measurement that increased the time of incubation. The

Table 1. Concentrations of carbon and nitrogen of soil at 10 cm of depth in different treatments.

Treatments	Carbon	Nitrogen Mg ha ⁻¹	C:N
Fallow	10.1a	1.12a	9.02
Without residues	9.7a	0.82b	11.83
Gramineae residues	9.8a	0.99ab	9.89
Leguminous residues	9.1a	1.01ab	9.01
Wild residues	9.3a	0.98ab	9.49

Numbers followed with different letter within the same column denote significant differences at $P < 0.05$.

lost carbon like CO₂-C, during the 65 days of incubation represented 0.6 and 0.9 % of the total C, for the treatments without residues, respectively. Similar values were found by Hernandez and Lopez (2002). According to the results obtained in this study, the application of vegetal residues has maintained the quality of the organic matter when

comparing with the fallow treatment, as it is indicated by the amount of mineralizable C. In agreement with Gregorich *et al.* (1994), the weatherable fraction of the organic matter of the soil contributes to the cycle of nutrients and the interphase between the autotrophics organisms that synthesize complex compounds of inorganic components, and of

Table 2. Distribution of the different fractions from the organic matter of the soil of agreement to the application of residues and minimum tillage.

Treatment	*MCM	**NMLC	C estable
		kg ha ⁻¹	
Fallow	123a	76.9b***	10023.1
Without residues	36c	87.4b	9612.6
Gramineae residues	35c	125.6ab	9674.4
Leguminous residues	60b	158.2a	8941.8
Wild residues	44bc	134.2ab	9165.8

* MCM Microbial Carbon Matter

** NMLC (not-microbial weakness Carbon) was calculated by the difference of weatherable potential carbon and originating carbon of the microbial matter.

*** the letters within the same column denote significant differences ($P < 0.1$) between the treatments.

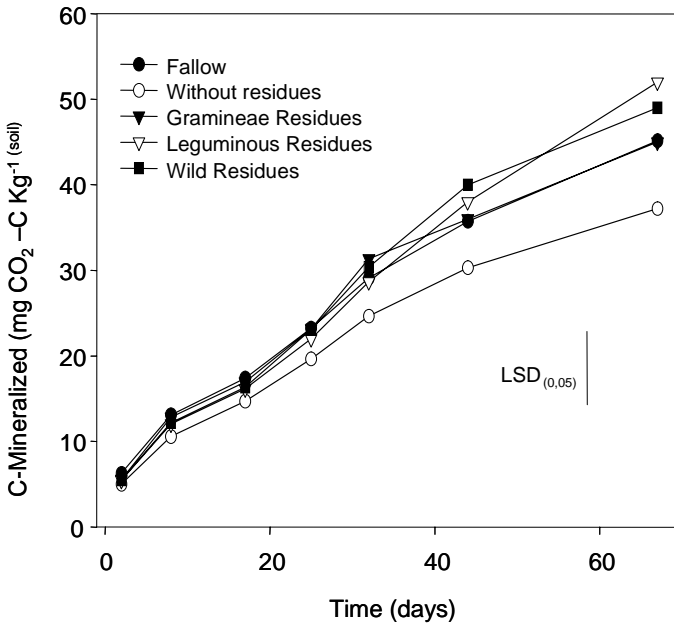


Figure 1. Mineralization of carbon of 0-10 cm depth from soil under fallow without residues and gramineae residues, leguminous and wild species.

heterotrophs organisms that disturb organic compounds and allow that the inorganic components again used. The organic C of the soil can be divided within active fractions (weakness) and resistant. Generally, the weakness fractions consist of sources of soluble C in water (sugar simple, organic acid and proteins), the microbial matter and its products, which are rapidly metabolized during the initial states of the incubation. The resistant fractions are composed containing lignin, humic acids, humate and fulvic acids of C physically protected. In table 2, the distribution of the different fractions from C in the different treatments is showed. The weatherable C [C-

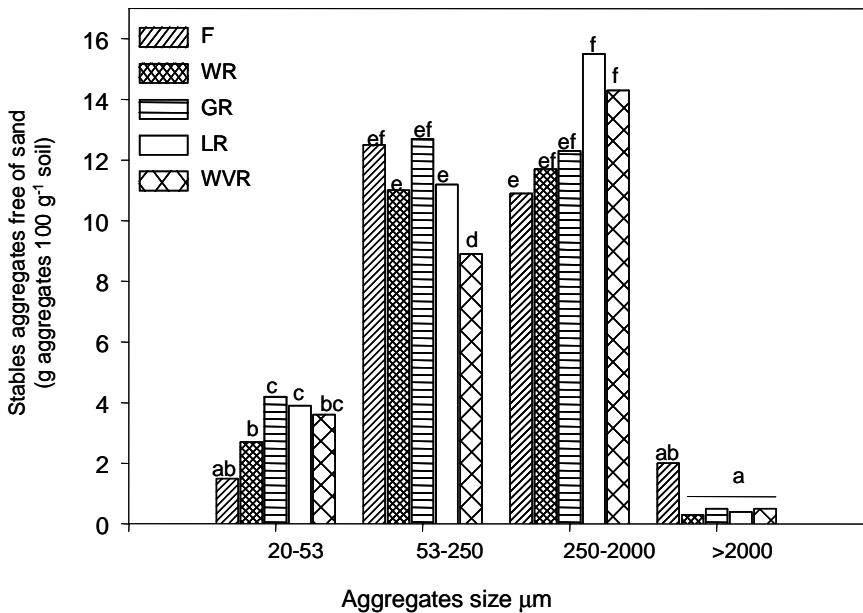
microbial] (MMC) and C- non microbial weakness (CLNM)] approximately represented 2% of total the organic C. The non microbial weakness C increased significantly with the tillage and the incorporation of L, which was greater 50% to comparing with the treatment of fallow. Nevertheless, this increase was similar to those where RN and G were applied. The stable C (total C-CLNM-MMC), was similar between the treatments, nevertheless, after three years to land cultivated the stable C diminished in 10% approximately.

Distribution of stable aggregates to the water

In general the effects of the soil

handling indicate, when comparing it with fallow, that all the treatments tend to lose macroaggregates > 2000 :macroadded m. This amount in approximately 60% as a result of the natural savannah change diminishes to agroecosystems (figure 2). The smallest macroaggregates (250-2000 :m) showed similar proportions in the treatments with the application of L, RN and G. The small macroaggregates seem to have increased due to the macroaggregates > 2000 :m. When correlating the macroaggregates (> 2000 :m) of the different treatments with the

biological division from the C, it was observed that the treatment with fallow, where exists a greater amount of macroaggregates, we found the smaller concentration of CLNM, and the greater one of stable C. The tillage diminished the amount of macroaggregates (> 2000 :m) (figure 2), consequently, the amount of stable C also diminished table 3). It is possible that this diminution of the concentration of the stable C has been product of the use of the CLNM that was stored in macroaggregates. According to Six *et al.*(1998), the tillage breaks macroaggregates and



Different letters means significant differences within the treatments and sizes of aggregates at P< 0.05

Figure 2. Distribution of soil aggregates into ultysol (0-10 cm) under different applied residues: fallow (F), without residues (WR), gramineae residues (GR), leguminous residues (LR), wild vegetative residues (WVR) and minimum tillage.

the organic matter that was within aggregates, and that is not incorporated and protected within smaller aggregates, which rapidly deteriorated. When is observed the treatments where residues was applied, it is possible to see that the CLNM greater is compared with treatments B and WW. Then the entrance of vegetal material to the soil seems to have increased the weakness fraction (CLNM), but this fraction was not within the aggregate, therefore, is quantified like CLNM and not like stable C. Even though the C in different aggregates from the soil was not determined, seems that great amount of weakness carbon present in the treatment under fallow is protected by aggregates of the soil and therefore it is quantified like stable C (table 3). In a study of the aggregate characteristics of vertisols in Venezuela (Espinoza, 2000), were great amounts of weatherable C in macroaggregates (> 250 :m) compared

with the microaggregates (< 250 :m). On the other hand, Hernandez and Lopez (2002) report a high production of $\text{Co}_2\text{-C}$ in macroaggregates comparing it with the microaggregates in ultisols of native savannahs in Venezuela. According to Elliott (1986), the macroaggregates tend to contain more organic matter and less sand, but is not clear if the organic matter in macroaggregates is weatherable than in the microaggregates. Freibauer *et al.* (1999) have demonstrated that in oxisols tropical the macroaggregates (> 2mm) are more sensitive to the land use, indicating a similar performance to those of soils in the tempered zones.

Mineralization of N into field

The observed rates of mineralization under optimal conditions in the laboratory are single potentials that rarely are obtained under conditions of field. In fact, under sub-optimal conditions of field the formation of weatherable fractions

Table 3. Distribution of different fractions of organic matter of the soil, according to the application and minimum farming.

Treatment	**MMC	*CLNM Kg ha ⁻¹	C stable
Fallow	12.3a	76.9b*	10023.1
Without residues	3.6c	87.4b	9612.6
Grass residues	3.5c	125.6ab	9674.4
Leguminous residues	6.0b	158.2a	8941.8
Native residues	5.4bc	134.2ab	9165.8

*CLNM (Carbon no-microbial) was calculated by the difference of potential carbon and the carbon coming from the microbial mass.

**MMC Microbial mass of carbon.

*** The letters inside the column show significant differences ($P < 0.1$) between the treatments

can be favored that can be deteriorated quickly under conditions of laboratory. In this study, the evaluation of the mineralization of N in the field was made using soil without vegetation and protected of rain. In the first 30 days of the experiment, the greater amount of mineralized N was observed where minimum tillage was not applied (fallow) (figure 3); nevertheless, at the end of the experiment (138 days) the N mineralized under this treatment increase only in 5% of the N mineralized to the 30 days. These results support the hypothesis of protection of the organic matter within macroaggregates $> 2000 \mu\text{m}$, as one considered in the results presented in figure 2.

The treatment where the greater amount of macroaggregates was observed ($> 2000 \mu\text{m}$), it is where

the period in evaluation is observed throughout a mineralization of approximately constant N. In the treatments where it was applied residues, a progressive increase of the N mineralized with the course of the time, compared with the treatment is observed significant control (MR.). The application of NV increased significantly ($P < 0,05$) in 50, 30 and 20% the N mineralized accumulated in 138 days, compared with the treatment MR., G and L, respectively (figure 3). The residues of wild and leguminous vegetation elevate the microbial activity (figure 1), and therefore, increase the mineralized nitrogen. Consequently, the microbial activity can be taken as an indicator of the mineralization of N into field. Mineralization of N without the application of wastes was not observed. This result indicates that

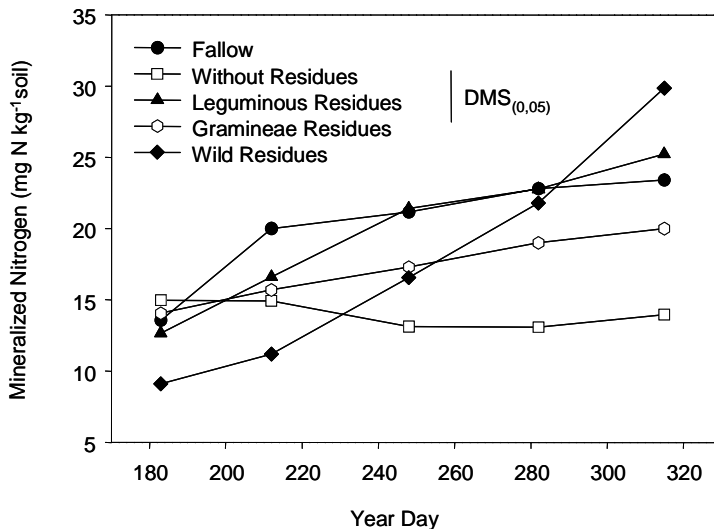


Figure 3. Mineralized nitrogen into field under applied different residues and minimum tillage, at 10 cm depth.

the dynamics of the incorporation of N within the organic fractions is governed by the quality of the

substrate. It seemed that the organic matter in the treatment without residues acts as N drain (figure 3).

Conclusions

The results of this research show that the traditional land use in these degraded savannahs drastically diminishes the originating C weakness of the microbial matter, as well as the activity of the microorganisms. A tendency exists to increase the microaggregation and soil. Nevertheless, the use of handling practices, such as the application of leguminous residues and wild vegetation increase macroaggregates (250-2000 μ m), which suggests a conservation of the entrances of C into the soil. Apparently in these degraded

soils, the weakness fractions of the organic matter also contain considerable amounts of N weakness and the stable fractions of C and N it seems to contribute to pool weatherable of these elements by the liberation of the stored organic matter in macroaggregates. The results reveal that the microbial matter of C, the microbial activity and not-microbial weakness carbon can be used as indexes of quality of organic matter of the soils to compare the effect in short time of the change of use of the soil highly meteorized.

Acknowledgment

The author wishes to express his gratefulness to the Ing. Agr. Marisol

López, for allowing the use of the field experiment for this research.

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