Dynamic Soil, Dynamic Plant ©2011 Global Science Books

Influence of Integrated Crop-Livestock-Forest Systems on Soil Organic Matter in Tropical Regions

Giovana Alcantara Maciel[1*] • Sandro Manuel Carmelino Hurtado[2] • Luiz Fernando Carvalho Leite[3] • Edvaldo Sagrilo[3] • Adriana Monteiro da Costa[4]

[1] Brazilian Agricultural Research Corporation, Embrapa Cerrados, Planaltina-DF, Brazil
[2] Fellowship CNPq. Planaltina-DF, Brazil
[3] Brazilian Agricultural Research Corporation, Embrapa Middle-North, Teresina-PI, Brazil
[4] Department of Geography, Federal of University of Minas Gerais, Belo Horizonte-MG, Brazil

Corresponding author: *** giovana.maciel@cpac.embrapa.br**

ABSTRACT

Soil organic matter (SOM) plays important functions in soil physical, chemical and biological processes. A reduction of SOM enhances the soil degradation process by reducing the biomass production and causing the loss of nutrients, water and soil. A mix of annual crops, tree species and pasture on the same area in an Integrated Crop-Livestock-Forest System (ICLFS) ensures abundant supplies of residues and an elevated amount of accumulated organic material in the soil thus constituting a promising alternative for tropical regions. Land areas aimed at fodder production, if well managed, produce large quantities of residues, which associated with a non-disturbed soil, favor the accumulation of SOM. In ICLFS, the cultivation of grain crops prior to the use of the land for pastures ensures more efficient use of residual nutrients by the plants, thus increasing the productivity of pastures. The adoption of technologies aiming at sustainability, as an improved soil management system, with better use of natural resources, increases the soil carbon levels. This condition results in the economic feasibility of cropping systems, through the improvement of soil, water and consequently, the environment quality. This chapter discusses the main advantages of integrated production systems and the influence of ICLFS on the supply and maintenance of SOM in tropical and subtropical regions.

Keywords: manage systems, no till, pastures, soil conservation
Abbreviations: CEC, cation exchange capacity; **EMBRAPA**, Brazilian Agricultural Research Corporation; **ICLFS**, Integrated crop-livestock-forest system; **NT**, no till; **OMS**, soil organic material accumulation; **SOM**, soil organic matter

CONTENTS

INTRODUCTION

The importance of soil organic matter (SOM) for soil physical, chemical and biological processes has been extensively discussed in the literature. SOM plays an important role in the conservation of the environment because it is linked to fundamental processes such as nutrient retention and cycles, soil aggregation and water flow. Moreover, SOM is the basic source of energy for biological activity (Silva and Mendonça 2007). A reduction of SOM can negatively interfere in such processes and result in a disturbance and degradation processes in the soil system and processes.

Because of the significant impacts that soil management systems have on environmental conditions, conservationist systems have been proposed with the objective of mitigating environmental impacts resulting from the production of food, fibers and energy. The no till system (NT) and integrated production systems such as the ICLFS are alternatives for sustainable production in tropical and subtropical regions (Landers 2007). Such systems combine the lack of

Received: 3 February, 2011. Accepted: 15 April, 2011.

Invited Mini-Review

physical revolving of soils with a high level of plant residual inputs, whether through annual grain crop rotations or a combination of pastures and forest species.

In order for SOM to effectively accumulate in the system, the C input rate must be higher than the decomposition rate (Moreira and Siqueira 2006). As a result, rotation schemes that lead to high residue production are targeted. In tropical conditions, high residue production is difficult to attain so it is important to use fodder grass to cover the soil. It is also important to diversify agricultural production, if forest and livestock components are included in the system (Vilela *et al.* 2003). An advantage of the ICLF system is that it supplies large amounts of residues to the soil covering for subsequent agriculture under the NT system. Adequately managed annual crops improve pasture conditions because they increase soil fertility, animal and biomass production (Anghinoni 2007).

This chapter discusses the main advantages of integrated production systems, in particular of the ICLFS, for the supply and maintenance of SOM in tropical and subtropical regions.

CONCEPT

An Integrated Crop-Livestock-Forest System (ICLFS) is an agricultural system which uses inter-cropping, rotational or successive cultures to produce grains, livestock, fibers, timber and crops on the same area in an integrated way (Kluthcouski and Yokoyama 2003). ICLFS increases the producer's income because it enables the producer to diversify activities and rationally maximize the use of natural resources. As a result, Brazil's agribusiness, which targets technical-economical feasibility, social justice, and the rational use of the environment, benefits from higher levels of competitiveness and environmental sustainability.

Although only recently qualified by the Brazilian Agricultural Research Enterprise (EMBRAPA), ICLFS is a very old technology. In family-based agricultural systems, with subsistence economy, there are situations related to bad weather, whereby production costs and income are maintained with the production of livestock, which is less vulnerable to climate changes than agriculture. Presently, ICLFS has been calling attention of researchers and the media because of its environmental awareness emphasizing the need to recover degraded areas and increase the production per unit of area in order to avoid further deforestation.

Integrated production systems can be established in different ways with mixed inter-cropping, crop sequencing (crop rotation) or strip cropping. Adding the forest component requires the cultivation of a native or exotic forest species and involves integrating forest and agriculture, forest, cattle and agriculture and cattle and forest. The trees are planted in alleys alternated with crops during the first years. When trees are enough developed so that animals are not able to damage them, pasture is grown and included into the system, allowing the forage production for cattle growing. The forest component adds diversity to the system along with a focus on sustainability. Some farmers face economic difficulties at growing forests, because it usually takes on average, a seven years period between the planting and cutting down of trees without economic returns. For such cases, ICLFS is a viable alternative because grain production at early stages finances the expenses with forest implantation.

The subsequent use of land for agriculture and then for pasture is a less intensive production system which is more beneficial in the long run, because of its effects on soil properties as the successive number of years of grazing increases (Broch *et al*. 1997). In Brazil, integrated production systems vary because of the country's vast territory. Advantages of the ICLF system are observed in the Cerrado, Caatinga, Amazon, Atlantic Forest and Pampas biomes, considering regional peculiarities and aiming at the best possible results.

An ICLF system should establish the best productivity combination in the summer and winter so that livestock production does not harm grain production, and *vice versa*. As a result, it is important to control animal grazing so as to optimize the use of pastures. It is also necessary to adequately manage pastures so that they are not excessively reduced and so that they can be used as covering straw for the implantation of no tillage agriculture in the summer.

OBJECTIVES AND BENEFITS OF AN INTEGRATED CROP-LIVESTOCK-FOREST SYSTEM

Recovery or reform of degraded pastures

In a crop-livestock-forest system, the production of grains finances at least partially, the recovery of pastures. Grains are cultivated during one, two or more years on degraded pastures. After this period, the areas go back to being pastures which benefit from the residual nutrients left by fodder production. It is necessary to manage the newly planted pastures though in order to prevent a subsequent degradation cycle. It is also important to point out that if maintenance fertilizing is not undertaken on most tropical region soils, the system will only work during the first two or three years. This happens because after the initial period, the nutrients that were added to the system through previous fertilizing will be depleted and the pasture will begin a new degradation cycle. It is therefore necessary to go back to planting crops on the area in order to replace nutrients (Kluthcouski and Yokoyama 2003).

Improvement of the physical and biological soil conditions of agricultural areas with pasture

Deeply embedded roots and dry grass produce considerable amounts of residues containing nutrients and organic material which improve the soil quality. This soil improvement characteristic resulting from ICLSF, is very important to prevent pasture degradation and the loss of vegetation and has a strong impact on the system's sustainability and productivity. This supports the claim that pastures are more efficient nutrient recyclers than grain crops (Greenland 1971; White *et al*. 1978; Vilela *et al*. 2003).

The production of pasture, preserved soil coverage and grains for animal feed during the dry season

In addition to producing silage and grains, the ICLF system allows pasture growing which was formerly produced to be used during the dry season. Liming the soil profile improves the development of the pasture root system, which then penetrates deeper into the soil, absorbing water at greater depths and strengthening its ability to resist during the dry season.

A decrease in the dependency on external inputs

Recovered or reformed pastures can contribute in greater amounts to animal diets. The grains produced on the farm are used in animal feed and this decreases the need to purchase animal food on the market.

A reduction in agricultural and livestock production costs

Higher productivity levels decrease proportionality of production costs and result in a lower incidence of weeds, a lower demand for pesticides and a more efficient use of labor.

Comfort and well being of animals

The forest component of integrated systems shades on the area which slightly decreases temperatures. This creates a friendly micro-climate to the animals and allows cattle to graze more comfortably. Studies demonstrate that productivity increases when cattle is less affected by thermal stress.

TYPES OF INTEGRATED CROP-LIVESTOCK-FOREST SYSTEMS

Certain ICLF systems are consolidated and widely used in Brazil, mainly in the Cerrado region. Some ICLFS schemes are described below.

Succession of cultures with annual coverings

After crops and grasses are harvested, pastures will be dormant until they present conditions for off-season use. In this case, the recently formed pasture is considered the second crop.

Another option is to cultivate plants for silage at the beginning of the rainy season. Before the rainy season is over, a second crop, tolerant to water shortage and able to grow rapidly should be planted. Sorghum and millet are species that present such conditions, especially when the objective is to only produce off-season silage.

Annual cultures and permanent pasture rotation

This is a more intensive exploitation system in which annual crop areas and permanent pastures are alternated every two or three years. Diagnosis, planning and previous assessment of all elements, including labor, equipment, available funds and management are decisive for success. This system presents benefits for both agriculture and pasture.

Restoration of pastures by means of annual cultures

This is a system used on farms where livestock is the main activity and characterized by inadequately managed pastures. In these systems soil fertility is usually low and it is necessary to use soil fertilizers. Within the ICLF concept an important example of this system is known as Santa Fé system. The Santa Fé system, was developed by Embrapa Rice and Beans (Kluthcouski, 2000). It refers to the intercrop of a grain crop, especially corn, with tropical grasses, mainly from the *Brachiaria* genus, although *Panicum* is also widely used. This system has considerable advantages because it does not alter the producer's activity calendar nor require special planting equipment. With this method, it is possible to increase crop yields and pastures on the mid-term and to decrease production costs thus enabling the farm to be more competitive and sustainable. In addition, soil covering for the no-tillage system is also provided.

Cereal planting procedures required are those traditional. In simultaneous planting, depending on the fodder species, seeds are mixed to fertilizers. The mixture must be prepared on the same day as planting and it is necessary to place the fertilizer and seed inside the ground at the same depth.

It is recommended to establish one or two additional cover crop lines between the planting lines so as to ensure better pasture development. However, this will depend on the availability of space and equipment. Another possibility is to delay planting of the cover crop until 20 to 40 days (depending on the specie) after the main crop emergency. In this case, when the cover crop is sown, the main crop will have already been established, thus minimizing competition effects. Once again, depending on the equipment, planting can be undertaken either by using machinery or through the NT system. In this case, a larger amount of seeds is necessary in order to guarantee the desired plant population. **Fig. 1A** shows *Brachiaria brizantha* cv. Murandu pasture at the moment of corn (*Zea mays* L.) harvesting and **Fig. 1B** shows the same pasture 30 days later, when grazing or cutting aimed at the production of silage or fodder is supposed to begin.

It is necessary to control invasive weeds, if they occur, by using specific herbicides as recommended for the specific culture. It is also important to associate forage management with the control of narrow-leaf weeds by using herbicide sub-doses in the implanted crop. Herbicide sub-doses cause stress to the forage and temporarily interrupt its growth. As a result, the forage does not compete with the main crop for nutrients and water during the critical competition period, which normally lasts up to 50 days. When the forage recovers from the stress, its development will be limited by the main crop, which is now well developed and is able to restrict the penetration of light. At the end of the main crop cycle, when senescence of leaves begins, the forage will grow rapidly. Therefore, harvesting of the main crop should not be delayed.

After harvesting, quick management of pasture formation should take place in order to stimulate the tillage of forage. After the animals are removed, the area must be closed off for 60 to 90 days, a period long enough to allow the pasture to grow depending on weather conditions. In case the culture is harvested for silage, the area is closed off for approximately 45 days to enable the pasture to recover. After this period, the cattle are allowed to graze. At the end of the dry season, the pasture is once again closed off and, at the beginning of the rainy season, it undergoes desiccation, thus beginning a new cycle of cultivation, preferably with no tillage.

In many cases, agricultural and livestock producers have used such technology only to recover pastures. Fertilizing for pasture maintenance and pasture control programs has made it possible to use new pastures for indefinite time periods with high productivity levels. Without ICLF the new pasture area will be degraded normally within a period of three years, thus requiring a new recovery process. It is important to highlight that the greater the degradation of the pasture, the higher the pasture recovery costs will be.

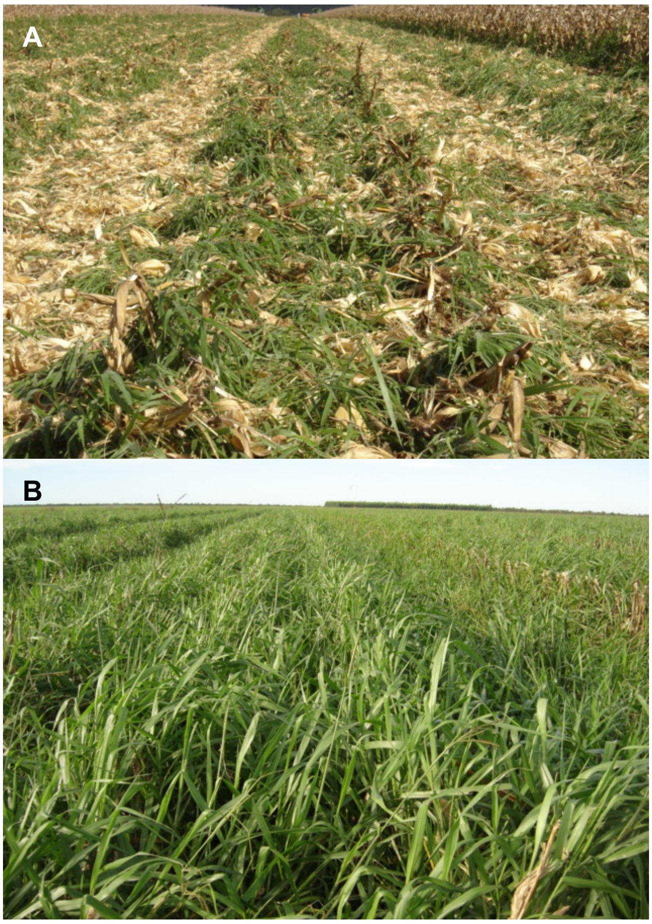

Fig. 1 (**A**) Pasture status (*Brachiaria brizantha* cv. Marandu) after corn (*Zea nays* L.) harvesting. (**B**) Pasture 30 days after harvesting, the ideal moment for starting grazing. Photos: Raimundo Bezerra de Araújo Neto

Cultivation in rows

In agricultural systems integrated with forest species, planting in rows seems to be the most promising method. This method consists of alternating forest alleys with annual crops during the first three years. After this period, the area destined for agriculture is then cultivated together with grass for grazing. The most widely used system, and that has presented the best results is the planting of corn and grass within trees alleys.

The distribution of the trees is an important structural element in ICLFS and must obey certain criteria such as the tree production's objective, the land slope and its exposure to direct sunlight, whether or not the other system components (agriculture and/or livestock) are protected, and water and soil conservation (Porfírio-da-Silva 2006, 2007).

In Brazil eucalyptus (*Eucalyptus* spp.) is the most widely used tree species because it grows relatively quickly and adapts well to the different existing biomes. Tracks are used for planting eucalyptus (tracks with three, five or seven rows of trees) interspersed with tracks for planting a grain crop, which later will turn pastures. Annual crops are planted between the rows and the width of the rows varies according to the size of the equipment available on the property, such as planters, pulverization bars, etc. A number of research projects are underway at Embrapa using native tree species and pesticides which, in the case of herbicides, must be applied carefully so as to avoid poisoning the trees.

INTEGRATED CROP- LIVESTOCK- FOREST SYSTEMS AND SOIL QUALITY

Despite its positive benefits, the ICLF system is still seen by some farmers with suspicion. Some farmers who have worked exclusively with crops have doubts about the system because of the possible damage that grazing can cause to the soils (e.g. compaction) and, consequently, to the productivity of crops following grasses. Soil compaction, though, is an inherent process of cultivation systems where no soil revolving exists such as the NT System and, therefore, it will be present in these systems, either in a larger or lesser degree (Stone *et al*. 2006). It is necessary to identify ways to reduce soil compaction and its effects by maintaining plant residues on the soil surface and increasing the amount of organic matter.

The contribution of vegetal biomass added to soil will be used according to the cultures. Because of their high biomass production and deep root system, forage grasses tend to add a greater amount of organic material to the soils. Among annual cultures, corn and sorghum are the species that most contribute with organic material. Nicoloso *et al*. (2008) obtained 6 t ha^{-1} of carbon produced by corn, and of 2.2 t ha^{-1} produced by soybean.

According to Leite and Galvão (2008), it is necessary to use plant cover crops that produce large amounts of plant residues, increase C inputs into the soil, insert nitrogen into the system (legumes) and that are well-adapted to the prevailing climatic conditions. Another promising alternative for the Cerrado region and specifically to the Brazilian Middle-North, is the use of Crop-Livestock integration, which ensures a high amount of crop residues and organic material to the soil.

In a long-term experiment (22 years) at Embrapa Cerrados, two cultivation systems were studied: one included an annual crop rotation (soybeans for 10 years and corn for 2 years and, after 12 years, these crops were rotated annually). The second cultivation system involved an annual crop/pasture rotation system (soybeans were grown for 2 years, followed by *Brachiaria humidicola* for 9 years, followed by soybeans again for 1 year and, after that, soybeans and corn were rotated annually). Soil organic carbon decreased under the soybean crop. However, at the last year, the organic carbon content in the soil covered with pasture was 30% higher than that of the annual crop rotation system (Sousa *et al*. 1997). From that point onwards, both soybean-corn rotation treatments using a disk plow and a light disk harrow showed a significant decrease in the soil organic carbon content (**Fig. 2**).

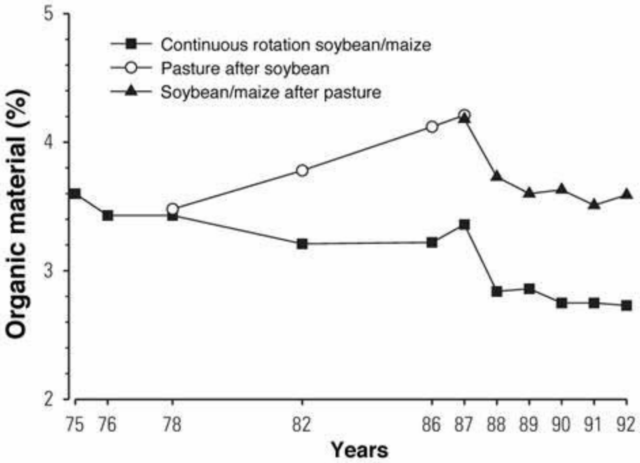

Fig. 2 The dynamics of soil organic matter from 0 to 20 cm depth in two crop rotation systems in a clay-texture red-yellow latosol. Source: Sousa *et al*. (1997).

Currently, there is no doubt that pasture is able to stock organic carbon in the soils, despite its high decomposition rate. This rate is counterbalanced by the formation of aggregates and physical protection of SOM pools, resulting from the pasture's highly developed and large deep root system.

Another factor that influences the amount of contributing material is the frequency with which animals are put to graze on the soil. On pastures characterized by less frequent grazing and a higher supply of grass, Nicoloso *et al*. (2008) observed a 50% decrease in the soil plant residues. Since grazing is required, it is necessary to adequately manage the grazing in order to balance out the system. A larger amount of organic material in the soil contributes to a better soil covering with more nutrients and improved soil quality.

Improved soil quality contributes to improved plant development, higher crop yields, higher animal productivity levels, larger profits for farmers, more intense land use, a smaller demand to clear up new areas for cattle grazing, greater environment protection and improved agricultural-forest sustainability systems. As a result, agriculture-forest integration is a promising alternative to recover degraded soils and pastures.

During the first years after such a system has been implanted and, in order to condition the soil to receive the system, it may be necessary to adopt management practices such as plowing and harrowing. These practices may initially change the soil structure and worsen the soil physical quality. As years go by, however, the presence of organic matter in the system will improve the soil quality and, therefore, the plant development. Plants create a favorable environment for the development of soil microorganisms which are extremely important for soil particle aggregation.

A higher accumulation of organic material in an agriculture-forest integrated system directly impacts the soil physical characteristics. Soil density is reduced, soil macroporosity and water infiltration are increased due to the presence of roots and microbial activity and consequent greater particles aggregation. The root's growth and decomposition over time help to create a canaliculum net in the soil, which is an important element for the water movement within the soil and for the plants development. Well nourished plants and a favorable chemical, physical and biological soil environment reduce the risk of water deficiencies during summer drought periods.

Soil and water conservation are fundamental issues in ICLS since cattle raising is considered the primary cause of the increase in soil degradation in Brazil. Large pasture areas are currently in advanced stage of degradation, resulting in loss of productive capacity. ICLS can recover such areas because it enables the accumulation of soil organic material, which promotes the soil re-structuring as well as the introduction of SOM in the production process. Maintaining straw on the soil surface improves the soil physical, chemical and biological attributes, thus increasing soil stability against erosion causing agents. The positive effects of organic material as soil covering can be direct by reducing the impact of rain drops and increasing water infiltration, and indirect, by improving the environment for the development of plants and microorganisms that will increase the soil quality over time. Thus, ICLS is a system that brings economic, social and environmental benefits to farmers and society as a whole. The magnitude of the system's benefits, however, depends on its adequate implantation and maintenance. The presence and maintenance of organic material covering the soil is fundamental to improve the soil physical, chemical and biological attributes.

SOIL ORGANIC MATTER (SOM)

Current agricultural development, which is very technical, continuously searches for higher productivity levels and is increasingly based on the supply of inputs as well as on a balance between the soil's physical, chemical and biological attributes. This balance is of special importance in cultivated areas in tropical regions, which are prone to quick soil degradation. In this context, efficient SOM management is very important for the sustainability of agriculture systems due to its beneficial effects on soil attributes and on the growth and development of plants.

Organic matter can be defined as the total amount of substances containing organic carbon in its composition, not considering non-decomposed residues of plants and animals. In practical terms, SOM can be divided into three main fractions: an active (fast mineralization) fraction, a fraction in decomposition (a source of cationic exchange), and a third fraction made up of living organisms. These parts are respectively considered light, soluble organic acids and more stabilized organic substances called humus and microbial biomass. For most soils, organic material content may vary from between 0.5 to 5.0% on the superficial soil layers. In general, SOM is important because, among other aspects, it generates electric charges in the soil, reduces the fixation of phosphorous, retains water in the soil, reduces soil erosion, makes pesticides more efficient, helps to increase the microbial population as well as the bio-availability of nutrients, which can be stocked or liberated through biological and physical-chemical processes, especially in the rhizosphere.

According to Meurer (2004), SOM compartments include organic matter of non-decomposed or in decomposition plants and animals, that exist on the topsoil, known as litter. It is important to highlight that the fraction of organic matter must be disregarded when evaluating soil fertility. The light fraction, or macro-organic matter, constitutes the largest SOM compartment and includes between 10 and 30% of organic carbon (Silva and Resck 1997). The organic matter content varies according to the type of soil, climate, management that is adopted and presents a smaller C:N ratio than that of litter. The alive fraction of SOM is made up of microbial biomass (MB) and it decomposes the residues that are added to the soil. These organisms compete with plants for nutrients by immobilizing them temporarily and then making them available after a period of approximately three months. Another important compartment is made up of the non-humic substances or bio-molecules (carbohydrates, amino acids, fats, resins), and low weight molecular organic tissues, continuously produced by the soil MB and rhizosphere. Such substances are important to interfere in acid-basic reactions, metal complexation and soil particle aggregation, although they present low persistence levels because they are rapidly attacked by microorganisms (Meurer 2004).

Finally, there are the humic substances which can be divided into humin (substances that are insoluble and are highly related to the soil's mineral fraction); fulvic acids (substances that are soluble in acid and basic mediums and that include a large presence of oxygenated functional groupings) and humic acid (substances that are insoluble in acid mediums which constitute the more stable reactive fraction of the soil organic matter (Canellas *et al*. 2000). In fact, most chemical soil reactions are due to this stable reactive fraction.

The different SOM compartments influence agricultural systems in a variety of ways by modifying soil physical, chemical and biological attributes. Chemically, SOM is known for its capacity to generate electric charges, increasing the soil cation exchange capacity (CEC). CEC is important for the nutrient retention process in colloids especially in environments characterized by low reactive clays and where SOM contribution can reach 90% of total. In this respect, humic substances have a main role because of the strong presence of carboxylic and hydroxylic functional groups in their structures. SOM is also important because of its capacity to complexate micro-nutrients and trace elements. Its potential to increase the soil buffering capacity, as well as its contribution to the availability of phosphate (P) and reduction phosphate fixation on the surface of the soil sesquioxides through the occupation of clay adsorption sites is another highly important attribute in tropical soils.

SOM acts physically both directly and indirectly on the soil aggregation process because of its intrinsic characteristics and properties and because of changes in the soil near the roots. The aggregation process indirectly affects the soil physical attributes such as density, porosity, aeration, water retention and infiltration capacity. The organic mineral complex CO, silicate and iron oxides (hematite and goethite) clays (Canellas *et al*. 2000) create micro-aggregates that enable the formation of greater aggregates and decrease or neutralize cohesion forces. Beutler *et al*. (2001) emphasized that the formation of the organic mineral complex, CO and silicate improve the stability of the soil aggregates. The soil water retention capacity and the quantity of water available in the soil – which are important characteristics for the movement and absorption of nutrients, along with the development of the roots and the productivity of the plant – are improved.

SOM shows high reactivity due to its large specific superficial area (up to 800-900 $m^2\ g^{-1}$), as well as high surface charge (between 400 and 800 $cmol_c\ kg^{-1}$) when compared to the main mineral clays present in the soil. Furthermore, SOM presents pH-dependent charges, which are predominantly negative in the pH band of soils. The soil (which received SOM) retains and provides nutrients to the plants much more efficiently.

Biologically, SOM is a source of nutrients such as N, P and S. As an example, it is known that the highest potentially available reserve of N in the soil is associated with the organic fraction. For each 1% of organic matter, between 20 to 30 kg of N ha^{-1} are released per year (Sousa and Lobato 2004). According to Zech *et al*. (1997), nutrients can interact with SOM as constituting organic complexes (N, P, S), inorganic cations (Ca, Mg, K), and as organically complexed cations (heavy metals and micro nutrients). The rate of nutrient mineralization depends on the decomposition rate of the different organic matter pools as well as on subsequent absorption by plants.

Soil microbiology is the main responsible element for organic residue decomposition for the nutrient cycle and for the energy flow within soil. Roots also have an important role because they release a large amount of organic and inorganic components to the rhizosphere. Among such components, are organic acids with low molecular weight as well as one or more carboxylic groups. It is a result of dissociation and the number of carboxylic groups that these acids can express a negative charge variation, allowing for metallic cations complexation in the soil solution and dislodgement of soil matrix anions. Humic substances have the capacity to form complexes with metallic ions due to the great number of carboxylic groups. In fact, organic acids originate from SOM decomposition or root exudation and have the capacity to complexate exchangeable aluminum as well as iron (Fe). A greater availability of P could be explained not only by the complex effect of humic acids on Fe and Al, but also by blockage of positive charges, through the occupation of the acids of the phosphate adsorption sites, an important characteristic in tropical regions. When the soil liming agent (CaOH), which has greater SOM quantities is applied to the soil surface, limestone moves within the soil with greater efficiency, thus correcting the soil's subsuperficial acidity and enabling the roots to penetrate more deeply into the soil when compared to soils that do not have plant residues (Franchini *et al*. 2001).

How and why ICLS improves SOM - the advantages of the system

An ICLF system integrates agriculture, livestock and tree species, either simultaneously or alternately (Young, 1991). The system influences the soil physical, chemical and biological attributes through inherent practices of each component of the system and contributes to control soil erosion, increase nutrient content and reduce the incidence of pest and diseases.

SOM plays a major role in the system in particular in soils that have undergone the effects from rain, sun, wind, and attacks of microorganisms. Additions to SOM content can be observed by managing fodder, which positively affects soil fertility and agriculture productivity through lower evaporation and water loss, higher nutrients cycling and greater efficiency in the use of fertilizers (Lustosa 1998; Carvalho *et al*. 2005; Fernandes *et al*. 2008).

The supply of organic matter will, nevertheless, depend on the kind of crop species that are used, as well as on the management of the pasture. Increases in organic matter content result from cultures that show a greater supply of plant material. Forages, in general, produce more dry material than other crops. Spera *et al*. (2009) observed higher plant dry biomass production in permanent pasture rotation systems (7.5 t ha^{-1}) than in systems only associated with grains. Lanzanova *et al*. (2007) reported an average contribution equivalent to 9.5 t ha^{-1} of dry matter with the cultivation of corn, and equivalent to 3.77 t ha^{-1} with the cultivation of soybean, thus highlighting the influence of crop species on the increase in soil plant material.

The adoption of crop-livestock integration and crop-livestock-forest integration systems has led to changes in parameters of agricultural productive systems. Among pastures, *Brachiaria* is one the species that has been subject of most research in Brazil. This is due to its high capacity to produce dry matter for fodder formation and its elevated C/N ratio (Fernandes *et al*. 2008), thus remaining present in fields as well as enabling adequate soil management practices. An example of this is the reduction of soil specific mass in the no tillage system, due to the higher SOM content thus creating better soil structure. **Fig. 3** shows the sowing of soybean (*Glycine max* L.) under no-till system in a soil covered by *Brachiaria brizantha* cv. 'Marandu' and **Fig. 4** shows a planting furrow in no-till in a sandy soil with less than 20% of clay in the west of Bahia, Brazil.

Pasture management has a large influence on the plant biomass production and consequently, on the organic matter content. Pastures that have undergone grazing have a reduced supply of organic material. Costa *et al*. (2009) reported an average dry matter production from ryegrass of 6.5 t ha^{-1} on non grazing systems. This amount was four times higher than that obtained on grazing systems, which had an average of 1,6 t ha^{-1} of biomass. In general, the amounts of biomass produced by pastures can be considered high if they were to be entirely integrated into soils; however, the need for using the biomass for animal consumption and for the production of silage reduces the organic material content that is added to the soil. Proper management of pastures becomes fundamental, so as to guarantee the production of biomass both for animals consumption and the soil surface.

Fig. 3 Soy (*Glycine max* L.) NT system on *Brachiaria brizantha* cv. Marandu forage. Photo: Giovana Alcantara Maciel.

Fig. 4 *Brachiaria brizantha* cv. Marandu forage and the furrow created by no tillage for soy planting. Photo: Giovana Alcantara Maciel.

Pastures contribute physically to soil conservation in agricultural areas because they reduce erosion effects, protect the soil from direct impact of rain and from solar radiation as well as increase water infiltration and moisture conservation. Pastures contain greater levels of lignin, leading to a better structure and stability of soil aggregates and resulting in higher production of carboxylic and humic acids (Kluthcouski *et al*. 2004). This directly influences the porous space and its relationship with the availability of nutrients, water, air as well as the development of the plant roots. Special attention is given to the soil porosity because it interferes in the gas exchanges between soil and atmosphere. When the soil has less pores it is more compact and has less oxygen, making root penetration more difficult. When the soil has more pores, it has more oxygen and it is easier for the root to penetrate the soil. The action of polysaccharides produced by mycorrhizal fungi associated with the roots of grasses improves soil aggregate stability (Kluthcouski *et al*. 2004).

It is important to highlight the role of soil biological activity on the mineralization of SOM stable fractions and on the aggregates stability (Spera *et al*. 2009). The contribution of macrofauna to the soil structure is related to the movement, soil revolving, digestion and excretion of organic material along with minerals deposited on the soil surface, thus contributing to the nutrient cycle of microorganisms (Lourente *et al*. 2007). By comparing conventional planting, NT systems, ICLFS and continuous grazing systems, the authors highlighted the existence of a greater population density of edaphic macrofauna in ICLFS and grazing systems.

The contribution of livestock to the ICLS also offers the opportunity to increase nutrient contents through the production of manure by animals, and, consequently, SOM levels are higher, therefore bringing physical, chemical and biological benefits to the soil.

On one hand, conservationist systems that do not revolve the soil tend to accumulate more organic matter. Costa *et al*. (2009) obtained higher amounts of total organic carbon (TOC) through conservationist preparation systems, with an average of 34.4 g C kg^{-1} soil, compared to conventional preparation systems (28.1 g C kg^{-1} soil). Soil tillage in conventional systems leads to fast mineralization of SOM through enhanced microbial activity, therefore reducing the contents of SOM.

On the other hand, inadequate management of pastures and/or inadequate agricultural practices can lead to soil degradation, resulting in less natural recovery, vigor and lower productivity levels. This together with the negative effects of animal grazing – which is proportional to the quantity of animals and the time that the animals remain on the pastures – significantly contributes to alter the soil physical attributes, thus reducing total and macro-porosity, and hydraulic conductivity, while increasing both soil microporosity and density.

In conclusion, available research results has reported that pastures regenerate degraded soils (Carvalho *et al*. 2005), reverting the negative effects of grazing and harvesting in the compacting of soils. In addition to improving the quality of soil, ICLF systems associated with NT results in economic, social and environmental benefits. Therefore, the ICLS can be considered a feasible strategy for increasing SOM and decreasing C emissions, in particular in tropical regions (Leite and Galvão 2008).

REFERENCES

Anghinoni I (2007) Fertilidado do solo e seu manejo em sistema plantio direto. In: Novais RF, Alvarez-V VH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL (Eds) *Fertilidade do Solo*, Sociedade Brasileira de Ciência do Solo, Viçosa, pp 874-928

Beutler NA, Silva MLN, Curi N, Ferreira MM, Pereira Filho IA, Cruz JC (2001) Agregação de Latossolo Vermelho Distrófico Típico relacionada com o manejo na região dos cerrados no Estado de Minas Gerais. *Revista Brasileira de Ciência do Solo* **25**, 129-136

Broch DL, Pitol C, Borges EP (1997) Integração agricultura-pecuária: plantio direto da soja sobre pastagem na integração agropecuária. Fundação Mato Grosso (*Informativo Técnico*, 01/97), Maracaju, 24 pp

Canellas LP, Santos GA, Moraes AA, Rumjanek VM, Olivares FL (2000) Avaliação de características de ácidos húmicos de resíduos de origem urbana: I. Métodos espectroscópicos (UV-Vis, IV, RMN 13C-CP/MAS) e microscopia eletrônica de varredura. *Revista Brasileira de Ciência do Solo* **24**, 741-750

Carvalho PC de F, Anghinoni I, Moraes A, Trein CR, Flores JPCL, Cepik CTC, Levien R, Lopes MT, Baggio C, Lang CR, Sulc RM, Pelissari A (2005) O estado da arte em integração lavoura-pecuária. In: Gottschall CS, Silva JLS, Rodrigues NC (Organizers) *Produção Animal*: *Mitos, Pesquisa e Adoção de Tecnologia*, Canoas-RS, pp 7-44

Costa A, Albuquerque JA, Mafra AL, Silva FR (2009) Propriedades físicas do solo em sistemas de manejo na integração agricultura-pecuária. *Revista Brasileira de Ciência do Solo* **33**, 235-244

Fernandes PCC, Grise MM, Alves LWR, Silveira Filho A, Dias-Filho MB (2008) *Diagnóstico e Modelagem da Integração Lavoura-Pecuária na Região de Paragominas*, PA. Embrapa Amazônia Oriental, Belém, 33 pp

Franchini JC, Meda AR, Cassiolato ME, Miyazawa M, Pavan MA (2001) Potencial de extratos de resíduos vegetais na mobilização do calcário no solo por método biológico. *Scientia Agrícola* **58**, 357-360

Greenland DJ (1971) Changes in the nitrogen status and physical condition of soils under pastures, with special reference to the maintenance of the fertility of Australia soils used for growing wheat. *Soils and Fetilizers* **34**, 237-251

Kluthcouski J, Aidar H, Stone LF, Cobucci T (2004) Integração lavoura-pecuária e o manejo da plantas daninhas. *Informações Agronômicas* **106**, 1-20

Kluthcouski J, Yokoyama LP (2003) Opções de Integração Lavoura-Pecuária. In: Kluthcouski J, Stone LF, Aidar H (Eds) *Integração Lavoura-Pecuária*, Embrapa Arroz e Feijão, Santo Antonio de Goiás, pp 130-172

Kluthcouski J, Cobucci T, Aidar H, Yokohama LP, Oliviera IP, Costa JLS, Silva JG, Vilela L, Barcellos AO, Magnabosco CU (2000) *Sistema Santa Fé – Tecnologia Embrapa: integração lavoura-pecuária pelo consórcio de culturas anuais com forrageiras, em áreas de lavoura, no sistemas direto e convencional*. Circular Técnica, 38. Embrapa Arroz e Feijão, Santo Antonio de Goiás, 28 pp

Landers JN (2007) *Tropical Crop-Livestock Systems in Conservation Agriculture: The Brazilian Experience* (Vol 5), Food and Agriculture Organization of the United Nations, Rome

Lanzanova ME, Nicoloso RS, Lovato T, Eltz FLF, Amado TJC, Reinert DJ (2007) Atributos físicos do solo em sistemas de integração lavoura-pecuária sob plantio direto. *Revista Brasileira de Ciência do Solo* **31**, 1131-1140

Leite LFC, Galvão SR (2008) Matéria orgânica do solo: funções, interação e manejo. In: Araújo ASF, Leite LFC, Nunes LAPL, Carneiro RFV (Eds) *Matéria Orgânica e Organismos do Solo*, EDUFPI, Teresina, 220 pp

Lourente ERP, Silva RF, Silva DA, Marchetti ME, Mercante FM (2007) Macrofauna edáfica e sua interação com atributos químicos e físicos do solo sob diferentes sistemas de manejo. *Acta Scientarum Agronomy* **29**, 17-22

Lustosa SBC (1998) Efeito do pastejo nas propriedades químicas do solo e no rendimento de soja e milho em rotação com pastagem consorciada de inverno no sistema de plantio direto. MSc thesis, Universidade Federal do Paraná, Curitiba, 84 pp

Meurer EJ (2004) *Fundamentos da Química do Solo* (2nd Edn), Gênesis, Porto Alegre, 290 pp

Moreira FM de S, Siqueira JO (2006) *Microbiologia e Bioquímica do Solo* (2nd Edn), Universidade Federal de Lavras, Lavras, 729 pp

Nicoloso RS, Lovato T, Amado TJC, Bayer C, Lanzanova ME (2008) Balanço do carbono orgânico no solo sob integração lavoura-pecuária no Sul do Brasil. *Revista Brasileira de Ciência do Solo (Viçosa)* **32**, 2425-2433

Porfírio-da-Silva V (2006) Arborização de pastagens: 1 - procedimentos para introdução de árvores em pastagens. Comunicado técnico 155, Embrapa Florestas, Colombo, 8 pp

Porfirio-da-Silva V (2007) Integração "lavoura-pecuária-floresta" como proposta de mudança do uso da terra. In: Fernandes EN, Martins PC, Moreira MSP, Arcuri PB (Eds) *Novos Desafios para o Leite do Brasil*, Embrapa Gado de Leite, Juiz de Fora, pp 197-210

Silva JE, Resck DVS (1997) Matéria orgânica do solo. In: Hungria M, Vargas MAT (Coordinators) *Biologia dos Solos dos Cerrados*, EMBRAPA-CPAC, Planaltina-DF, pp 467-524

Silva IR, Mendonça ES (2007) Matéria orgânica do solo. In: Novais RF, Alvarez-V VH, Barros NF, Fontes RLF, Cantarutti RB, Neves JCL (Eds) *Fertilidade do Solo*, Sociedade Brasileira de Ciência do Solo, Viçosa, pp 275-374

Sousa DMG, Lobato E (2004) Adubação com nitrogênio. In: Sousa DMG, Lobato E (Eds) *Cerrado: Correção do Solo e Adubação*, Embrapa Cerrados, Planaltina-DF, pp 129-145

Spera ST, Santos HP, Fontaneli RS, Tomm GO (2009) Integração lavoura-pecuária e os atributos físicos do solo manejado sob sistema plantio direto. *Revista Brasileira de Ciência do Solo* **33**, 129-136

Stevenson FJ (1994) *Humus Chemistry: Genesis, Composition, Reactions* (2nd Edn), John Wiley & Sons, New York, 496 pp

Stone LF, Silveira PM, Moreira JAA (2006) *Atributos Físico-Hídricos do Solo Sob Plantio Direto*, Série Documentos, Embrapa Arroz e Feijão, Santo Antônio de Goiás, 39 pp

Vilela L, Macedo MCM, Martha Jr GB, Kluthcouski J (2003) Benefícios da integração lavoura-pecuária. In: Kluthcouski J, Stone LF, Aidar H (Eds) *Integração Lavoura-Pecuária*, Embrapa Arroz e Feijão, Santo Antonio de Goiás, pp 143-170

White DH, Elliot BR, Sharkey MJ, Reeves TG (1978) Efficiency of land-use systems involving crops and pastures. *Journal of the Australian Institute of Agricultural Science (Sydney)* **44**, 21-27

Young A (1991) *Agroforestry for Soil Conservation*, CAB International, New York, 276 pp

Zech W, Senesi N, Guggenberger G, Kaiser K, Lehmann J, Miano TM, Miltner A, Schroth G (1997) Factors controlling humification and mineralization of soil organic matter in the tropics. *Geoderma* **79**, 117-161