Factors influencing on nutrient recycling in permanent grasslands and development of their modeling

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This review examines studies on factors influencing on nutrient recycling in permanent grasslands: soil organisms, litter, radicular systems of grasses and animal excretions. It also analyzes the evolution of researches aimed to modeling the recycling process. Some considerations and recommendations are also stated for further researches on this subject.

Key words: *permanent grasslands, nutrient recycling, modeling*

INTRODUCTION

Soils of permanent grasslands have the largest accumulation of OM within the first 15 cm, which mainly comes from litter of the green covering and from roots that die and then grow again (Liu 2006).

The largest population and biological activity of the soil coexists in this layer, which is the most superficial. Worms, coleopteran, coprophagous, termites, hymenopterans, fungi, actinomycetes and bacteria have larger populations and interact in the general activity of organic matter decomposition and energy transference, where the internal nutrient recycling of these ecosystems is mostly produced (Cabrera *et al.* 2011).

Animal excretions, volatilization of N within them, nitrate leaching, rain water and others are essential for nutrient recycling (Rodríguez *et al.* 2005 and Rodríguez *et al.* 2008).

The objective of this review is to carry out an updated analysis of the functioning of different ways of recycling nutrients in permanent grasslands, and of the state of knowledge regarding modeling and simulation of this process.

MAIN FUNCTIONS OF SOIL ORGANISMS IN RECYCLING NUTRIENTS

The activity of the different functional groups that compose the soil macrofauna, such as worms (soil engineers), dentritivores, herbivores and predators, allow the regulation of edaphic processes and functioning and balance of the ecosystem(Zerbino *et al.* 2008).

When researching the functional composition of edaphic macrofauna in four different land uses, in which permanent grasslands are included, Cabrera *et al.* (2011) confirmed that, in most cases, worms and/or dentritivores had higher density and dentritivores and/or herbivores had higher biomass in occidental provinces of Cuba. Proportion among functional groups depended on the intensity of land use, disturbance level of the edaphic environment and resources availability. In the quoted study, the Coleopteran order had the highest variety of all the functional groups (predatory, herbivorous and dentritivorous families) in soils with permanent grasslands and influence of larvae and adults.

Villalobos (2000) pointed out that each development stage (larvae or adult), in different soil organisms, has an exclusive function in the edaphic environment. These authors also highlighted Elateridae and Melolonthidae as the most common families of Coleopteran, with larvae and/or adults within the edaphic profile. Other important families are Curculionidae, Tenebrionidae, Nitidulidae, Carabidae and Staphylinidae (Menéndez 2010). Coleopteran larvae, with their habit of endogeous life, can be involved in the transformations of soil physical properties, and adults mainly use the useful resources of the surface.

Coprophagous coleopterans (Scarabaideae) are insects that actively participate in nutrient recycling, which turns them into an essential element of ecosystems. When they burry themselves and consume excretions, these coleopterans increase the rate of nutrient recycling and soil aeration (Martínez *et al.* 2011). Dung decomposition within grasslands provides nutrients to soils, which benefits and increases pasture productions (Aarons *et al.* 2004 and Rodríguez *et al.* 2005).

Dung degradation depends on biotic factors, like coprophagous fauna, and on abiotic factors: temperature, rain and soil humidity (Arduaga and Huerta 2007 and Yamada *et al.* 2007). Insects, dung beetles, ants, termites, and flies mainly participate among the biotic factors, but there are some other animals, like worms and earthworms (Freymann *et al.* 2008).

The composition of this fauna varies according to climatic and regional conditions. Dung beetles and worms are the main dung degrading animals of temperate areas, while termites have an active participation in dry tropical areas (Freyman *et al.* 2008). Instead, dung beetles have a wide participation in humid tropical areas (Yamada *et al.* 2007).

The speed of dung disappearance in grasslands depends on the season in which it is deposited on the soil. In tropical areas, degradation process is fast, but varies depending on the season. In Nigeria, during the rainy season, 80% of the dung is degraded after six weeks, while only 5 % in the same time during dry season (Omaiko 1981). Similar dung decomposition rates, during both seasons, have been found by Rodríguez *et al.* (2003) in Cuba, and more recently by Crespo (2013). However, in Costa Rica, 70 % of the dung is degraded after seven weeks during rainy season while only 30 % is degraded after the same time during dry season (Herrick and Lal 1996).

In tropical areas of Veracruz, Mexico, where the fauna of coleopterans is abundant and diverse (Montes de Oca 2001), most of the cattle dung degradation in the rainy period was performed in the first four and eight days after its deposition. In this period, dung beetles *Euonitricellus intermedius*, *Digitonthophagus gazella* and *Copris incertus* were more abundant. Dung degradation was slower during dry periods than during rainy periods. Abundance of dung beetles was also lower during dry periods, although *E. intermedius* and *D. gazella* were still present.

Among the microorganisms, actinomycetes have an important role in sustainability of natural and agricultural systems. They participate in decomposition of OM and recalcitrant compounds, like lignin and take part of the biological fixation of N, agrochemical degradation, and plant and animal control. Cardona *et al.* (2009), in Colombia, found that abundance of actinomycetes varied depending on vegetation type and soil depth, presumably associated to the presence of worms and to other physical and chemical characteristics, related to soil fertility, like OM content, total changeable basis and cationic exchange capacity. Estreptomices genre was the most abundant in all studied cases. According to Boudemagh *et al.* (2005), 75 % of total population of the species belonging to this genre has the ability of producing molecules with antibiotic activity. In all studies, the highest amount of actinomycetes has been found between 1 and 20 cm deep.

Researches carried out in tropical grasslands have demonstrated that animal production systems, based on the use of improved pastures in association with legumes, have had a positive effect on macrofauna activity and, specially, on worm population, which increased its biomass from 4.8 to 51.1 g/m^2 (Decaens *et al.* 2001). In a research carried out in Peru, Sánchez and Ara (1989) found that the population of organisms within the soil increased after six years of grazing in a management system of *Brachiaria decumbens*, associated with *Desmodium ovalifolium*. These authors found that invertebrate fauna increased from 194 to 346 individual/m^2, when a rotational grazing system was applied for four consecutive years, and soil was fertilized by itself due to animal depositions and litter. This result was improved after the introduction of tree legumes in these areas, which provided a proper microclimate that favored a higher colonization of individuals from macrofauna, specially, the presence of orders with great economic and ecological importance, like earthworms and coleopterans (Sánchez and Milera 2002).

Rodríguez *et al.* (2002) pointed out that the establishment of *Leucaena leucocephala* in Cuban grasslands increased macrofauna populations from 36.28 individuals/m^2 (area without *L. leucocephala*) to 181.28 individuals/m^2 (area with *L. leucocephala*) and also its biomass from 11.89 g/m^2 to 41.49 g/m^2. This was mainly related to the quality of litter produced by this legume, although other factors may also have influenced on this result, like climate regulation, diversity of species and the superior soil humidity retention. Hernández and Sánchez (2006) evaluated the performance of different chemical and biological indicators in a wide amount of cattle rearing units from occidental areas of Cuba and found that introduction of trees in grasslands contributed to increase density and biomass of individuals from soil macrofauna, which influenced on nutrient content. After ten years of exploitation, soil of silvopastoral systems presented higher content of organic matter, compared to monoculture of grasses. Dueñas *et al.* (2006) also found similar results.

Regarding functional aspects of organism diversity in grasslands, Bardgett and Walker (2004) stated management strategies directed to manage soil biota to stimulate resilience in autorregulation of the ecosystem. Out of these researches, it can be inferred that grassland systems are optimal for increasing biological diversity of soil and achieving functional autorregulation of the ecosystem. Further studies are needed for demonstrating the hypothesis that soil biodiversity is positively related to stability and for clarifying the relations among productivity, community integrity and functioning of soil biological communities.

MAIN FACTORS INFLUENCING ON NUTRIENT RECYCLING FROM GRASSLAND LITTER

Litter constitutes the main entrance of soil nutrients of grasslands and it is one of the main points of recycling organic matter and nutrients. Litter is the accumulation of green residues (leaves, stems, inflorescences, etc.) on soil surface (Sánchez *et al.* 2008). Litter is distributed all over the grazed area and contributes significantly to nutrient and energy flow, as well as to the constitution of humid reserves of soil. It is known that it feeds trophic chains in which decomposer and consumer organisms are followed. Corpses of both types of organisms and consumers depositions feed another level of analogue structure and so on, until the energy of initial contributions is exhausted (Trofymow *et al.* 2002).

Liu *et al.* (2006) found that physical and chemical conditions of soil controlled litter decomposition in two types of grasslands in Mongolia, China, with very marked effects on the contents of N, P and water from 1 to 15 cm deep.

According to Sánchez *et al.* (2008), during the process of litter decomposition, the labile fraction (sugars and proteins) is released first and later, the recalcitrant fraction, which has a slower decomposition, like lignin and phenols. According to these authors, there are three main stages in the cycle of litter decomposition. During the first stage, fast biodegradation of most of polysaccharides and water-soluble substances is produced due to microbial action and rain-washes. In the second stage, the slow decrease of phenolic water-solubles and hemicelluloses due to fragmentation, transport, mixture, and biodegradation, because of the action of the edaphic macrofauna. In the third stage, there is an increase of lignin and protein content due to mineral and humic transformation, with a lixiviation of newly formed water-solubles. This remarkably delays decomposition speed. Liu *et al.* (2006) stated that nutrients released during litter decomposition represent between 70 and 90 % of all nutrients required per plant. Therefore, decomposition rate is the factor determining biomass and productivity of these ecosystems.

Cellulose, hemicellulose and lignin are the most important components of litter and represent between 50 and 80 % of the dry matter (Berg 2000). Before its assimilation by microorganisms, these macromolecules have to be hydrolyzed to simpler units, by means of extracellular enzymes.

Hydrolysis of cellulose to glucose units is carried out by cellulase enzymes. After cellulose, lignin is the second most important component of litter. Lignin is a polymer composed by units of phenylpropene with multiple bonds, and it is degraded by a complex of enzymes, like laccases, lignin peroxidases and tyrosinases, which work synergically (Fioretto *et al.* 2005). Grass species have a great difference according to the amount and quality of litter they produce (Bardgett and Walker 2004). Generally, C/N and lignin/nitrogen relations of grasses are higher than those of legumes, which delays decomposition.

Plants with a high C/N relation (higher than 25) form a stable cover that contributes to the increase of organic matter content, and, consequently, to improve soil structure and to protect it from rain and solar radiation. This high C/N relation also favors the development of the radical system, nodule formation and symbiotic fixation of nitrogen. Plants with less than 25 of C/N relation have a faster mineralization (Yadava and Tabouda 2008). Studies carried out in Cuban grassland ecosystems indicated that decomposition rate of litter shows marked variations among grass species, and it is faster in legumes than in grasses (Crespo 2013).

According to Sánchez *et al.* (2007, 2008), dynamics of litter decomposition was more intense in the silvopastoral system than in the monoculture of grasses. Speed varied within the following order: *Leucaena leucocephala* > *P. maximum* in the silvopastoral system > *P. maximum* in the monoculture system. After 210 d, only 3.12 % of leucaena litter remained without decomposing. However, in a similar time, guinea litter of this system still represented 28.2 % of the initial weight and was much lower than the reports for this same species in the monoculture system (45.3% of initial weight). This may be associated to the favorable microclimate created, in the first systems, by the presence of trees, which favor the activity of decomposers.

These results show that the introduction of tree legumes within grasslands is very important for achieving litter productions of different nature, which provides an intermediate C/N relation. This favors the humic reserve of soil and guarantees a slower mineralization of nitrogen. All this leads to a higher synchrony between processes of nutrients, easily available, and the humus content of soil. According to Ruiz *et al.* (2003) and Alonso *et al.* (2004), trees have increases soil fertility in cattle rearing areas of Cuba, through production and decomposition of litter and cutting residues. Nevertheless, Palm and Sánchez (1991) found differences among legumes in litter decomposition, in a way that, decomposition and nutrient release of Erythrina spp was significantly faster than that of *Inga edulis* and *Cajanus cajan*, due to the presence of low contents of polyphenols in their leaves. These changes are related to colonization and activity of the decomposer fauna (Hunter *et al.* 2003 and Barajas-Guzmán and Álvarez-Sánchez 2003).

Bacteria and fungi are organisms that decompose litter, participate in the first stages of decomposition and consume mainly sugars and amino acids (Cardona *et al.* 2009). While decomposition advances, the process is slower and specialized septate fungi participate, like Ascomycetes, Basidiomycetes and Actinomycetes, because they can degrade cellulose, lignin and more complex proteins. Dentritivore organisms are consumers that consume detritus and the populations of microorganisms associated to it.

Because the percentage of grass used by ruminants in grazing may vary between 40 and 60 % (Thomas 1992), the return of green nutrients to the soil, through grassland litter, can be higher than that which is integrated by animal excretions. This return of nutrients to the soil and the following recycling, as plant intake, can be manipulated through the selection of grass species that produce a large amount of litter with easy decomposition. This can be managed in a way that supply of nutrients to soil and grass demand can be synchronized through this means (Koukoura *et al.* 2003 y Sánchez *et al.* 2008).

For developing this management, proper knowledge about decomposition and release of litter nutrients from different plant species that compose grasslands is required. Studies of Gupta and Singh (1981), Bruce and Ebershon (1982) and Palm and Sánchez (1990) show information about litter decomposition of tropical legumes and grasses. In silvopastoral systems, litter production is higher in the ecosystem than in grasslands without trees, which may represent and important proportion of nutrients needed for the herbaceous stratum, and contribute to maintain productivity of grasslands (Pentón 2000 and Sánchez *et al.* 2008).

ROOT INVOLVEMENT ON NUTRIENT RECYCLING OF GRASSLANDS

Knowledge of C accumulation processes in grasslands, introduced in tropical savannas, has been limited due to lack of researches on production, dynamics and decomposition of roots.

Grasslands introduced on plains from the East of Colombia have demonstrated that accumulate substantial amounts of OM, regarding species of replaced native savannas (Trujillo *et al.* 2006). Accumulation of soil organic carbon (SOC), inhabited by any plant community, depends on primary net productivity (PNP) of plant community. In many grasslands, the main mechanism of C deposition, at few cm below the soil, occurs through root production, their mortality and decomposition. Therefore, researching on root production and their performance is essential for understanding the dynamics of C within the soil.

Long *et al.* (1989) measured PNP in five grasslands from Mexico, Kenya, Thailand, China and Brazil. These authors found that the PNP of these five grasses, with inclusion of roots at 15 cm deep, averaged from 14 to 100 Mg/ha^{-1}d^{-1}, and concluded that these natural grasslands are places for potential net accumulation of C. There are also indirect evidences stating that, under the soil, the biomass PNP (BPNP) is higher in introduced grasslands than in isohypertherming native savannas from Colombia.

Compared to regions with temperate climate, researches on radicular biomass and other subterranean components in grasslands have had low development (Pérez-Quesada *et al.* 2011). Nevertheless, in tropical savannas, Lamotte (1975) performed several studies on this subject in Africa. In Cuba, Hernández and Rodríguez (2001), Lok *et al.* (2009) and Rodríguez *et al.* (2013) carried out some researches in several grassland ecosystems.

Genetic characteristics of pastures (Pengelly and Hecker 1988), plant age (Gómez-Karabalí *et al.* 2010), climate (Walter *et al.* 2012), and chemical and physical properties of soil (Vilche *et al.* 2000 and February and Higgin 2010) are among the factors influencing on radicular development of grasslands. Therefore, there is a marked variability in subterranean phytomass production of different grasslands. Values between 345 and 230 g m^{-2} have been found in Venezuela (Medina 1982) and in South Africa (Huntley and Morris 1982). While in Cuba, mean values of 667g m^{-2} have been found in six grasses (Yepes and Alfonso 1972), from 564 to 1334 g m^{-2} in *Cynodon nlemfuensis* (Hernández *et al.* 1988) and from 1,000 to 1,131.85 g m^{-2} *Panicum maximum*, respectively (Crespo and Lazo 2001). Recently, Rodríguez *et al.* (2013) found values between 571 and 3,929 g m^{-2} in six grassland ecosystems from Mayabeque province, Cuba.

Some studies have concluded that, in systems of grasses/legumes association, the radicular system of grassland shows higher volume of radicular biomass than pure grasslands of grasses. This has been related to the great accumulation of OM and total N within the soil (Lok *et al.* 2009 and Eckeren *et al.* 2010). February y Higgin (2010), in researches with isotopes (^{13}C and ^{15}N), demonstrated that biomass production of roots from a grassland is related to the content and space distribution of N in the soil, and it is inversely proportional to its humidity.

Although Martuscello *et al.* (2009) found a negative influence of shade level on root phytomass in silvopastoral systems, Carrilho *et al.* (2012) demonstrated the opposite. This indicates that new researches are necessary to know root performance in these systems. High BPNP or high OM entrance does not necessary leads to a higher accumulation of SOC, if decomposition rate is proportionally higher than that of native savannas. Accumulation of SOC in introduced grasslands may take place only if decomposition rate of the new accumulated OM is the same or lower than in native savannas.

Studies carried out in Cuba by Crespo and Lazo (2001) have indicated that root systems, in grasslands, has contributed to the ecosystem, with contributions between 19 and 33 kg N/ha, from 3 to 5 kg P/ha and between 1 and 2 kg K/ha annually.

EFFECT OF ANIMALS ON NUTRIENT RECYCLING

Intensive management of grasslands is considered as a vital aspect of recycling plant nutrients. Redistribution of nutrients within cattle excretions and urine produces favorable effects on grassland productivity, with the efficient conversion of grass into animal product, which adds sustainability to these systems (Clark *et al.* 2011).

Cattle may be beneficial or harmful for grasslands. The most harmful aspect is, mainly, the physical action of trampling. Several factors interact and determine the potential damage that may produce this effect. Aspects like humid content of soil, its physical properties, type of forage, stocking rate, and amount of grazing days have a considerable influence on paddock management. These factors may be managed for minimizing harmful influence of trampling (Amézquita 2004).

When grassland soil is very humid, cattle weight will compress it to smaller volumes, which increases density (weight per volume unit). This action decreases soil volume in areas where roots storing oxygen and water (porous space) are developed, which limits the radicular volume of plants (Broersma *et al.* 2004).

The effect of trampling is higher on superficial soil, and this may produce a reduction of its water and air contents because its permeability decreases. A low water infiltration rate may produce a high rate of run-off with heavy rains and, therefore, a higher hydric erosion of soil, which is a problem associated with overgrazing (Aarons *et al.* 2004).

The forage nature can also affect the amount of damage caused by animal trampling. Forages with a prolific radicular system, within the layer between 15 and 25 cm deep, can endure trampling effect better than those forages with low mass of roots (Petersen *et al.* 2007). However, pasture itself can be physically affected by trampling. In this sense, non rhizomatous and non stoloniferous species (Panicum genre) may be greatly harmful, regarding rhizomes/stoloniferous (Digitaria and Cenchrus genre).

Stocking rate and time for grazing will influence on the amount of damage caused by trampling. Keeping animals out of the fields when the soil is wet or, if it is not possible, locate them in less humid areas, with lower stocking rate (Petersen *et al.* 2007) can minimize this affectation.

High volume of excretions and urine deposited in paddocks is a positive aspect of high intensity of grazing. Besides nutrient recycling, organic matter of excretions will increase its accumulation in the soil, which will improve its physical properties.

One of the obvious consequences of animals in the grassland is the aggregate value they provide because nutrient contents of ingested pastures are moved from one area to the other. Most of the estimates indicate that only 25, 20 and 15 % of N, P and K, respectively, present in the pasture is retained by the animals and used it in their different metabolic events. This means that around 75, 80 and 85 % of N, P and K, respectively, go through the animal and is excreted by feces and urine. Therefore, most of ingested nutrients are recycled many times in the grassland ecosystems (Rodríguez *et al.* 2005).

These nutrients, recycled over the grassland, can be turned into assimilable shapes for plants. However, these excretions have no uniform distribution within the paddocks which leads to a less efficient recycling of nutrients (Crespo 2013).

In order to determine the way in which recycling is produced, it is useful to know the frequency in which animals defecate and urinate daily, as well as the grassland area they cover. Generally, each bovine produces 10 defecations daily, which cover an area of around 2 m^2, as well as eight urinations that cover 3.8 m^2 (Rodríguez *et al.* 2005). There are marked differences on the nutrient contents of both types of excretions. So, around half of N removed by animals is produced by urine and the rest is eliminated by the feces. This proportion can be increased up to 2/3 in urine, if animals graze in grassland with high N content (well fertilized grasses with N or legumes), which contribution is above their requirements (Sánchez *et al.* 2008).

Almost all N of urine is presented as urea, which performance is just like that of commercial urea, because it experiences some losses due to volatilization (Bolan *et al.* 2004).

The N of excretions, which includes plant and microbial protein, has several organic structures, which can remain within the soil for several weeks, months and, even, years. Contrary to P, most part of K goes through the animal within urine, and is considered as an effective potassium fertilizer, which is immediately available for plants (Hutchings *et al.* 2007).

Other factors influencing on distribution of animal excretion on grasslands are: tree shades, land falls or slopes, time of grazing, water sources, places for supplementary food supplies, stocking rate density and some others (Cabrera 2003, Alonso 2004 and Chadwick *et al.* 2011). These factors influence on efficiency of nutrient recycling and may increase their lixiviation and transportation of fecal materials and harmful bacteria towards water sources after heavy rains.

SIMULATION MODELS OF NUTRIENT RECYCLING

The first studies for simulating nutrient recycling in livestock developed model that only comprehend isolated aspects of this process, like accumulation models, biological fixation of N, volatilization models of N from fertilizers and excretions, models for nitrate lixiviation, and some others. Nevertheless, only few studies have tried to simulate nutrient recycling among the different components of cattle rearing system (flow through soil, grassland, animals and atmosphere) (Goulding *et al.* 2008).

Yasso model (Liski *et al.* 2005) describes litter decomposition from climate reports and quality of litter from several parts of the world. With this model, litter decomposition rate, rich in phenolic compounds, was systematically overestimated while those rich in O-alkyl compounds (grass leaves) was underestimated. Besides, taking only into account the initial concentration of N did not improve the accuracy of the model, but, considering also lignin initial content (non hydrolysable acid residue), this accuracy was achieved.

This model has been already applied as a module in CO_2FIX, which is a general model for estimating carbon balance and ability of C collecting in several ecosystems (Schelhaas and Nabuurs 2001 and Massera *et al.* 2003).

O Connor (2009) examined the different models that simulate N balance in cattle rearing systems extensively managed. This author stated that each researcher represented the N cycle according to their points of view. So, under New Zealand conditions, cattle is identified as herbivorous, and legumes as N fixers. Dead green material is considered as litter component, while others have divided plant components into live and dead aerial part, crowns and roots, in order to represent low meadows of grasses in Colorado.

Several studies have modeled N flow in grassland ecosystems from microbial activity of soil (McGill *et al.* 1974, McGill *et al.* 1981 and Woodmansee and Wallade 1981), biological fixation of N (Paul and Juma, 1981, Jones and Woodmansee 1979 and Bate 1981), and evolution of nitrate and ammonia contents of soil (O'Connor 1974, 1981 and Woodmansee and Wallade 1981).

In systems of intensive management of cattle, several researchers have tried to model different gaseous losses of N and its effect on greenhouse gases emission. Some others have analyzed losses of this element due to run-off or lixiviation, as well as due to the effect of animal management.

It is known that lixiviation of nitrates (NO_3) and emissions of NO_2 are high in grassland areas where animals excrete and urinate (Rodríguez *et al.* 2005). However, the estimate of these greenhouse gases emissions is biased due to heterogeneity in which excretions are distributed by animals over the grasslands (Hustchings *et al.* 2007). FASSET model, created by Hustchings *et al.* (2007), allowed obtaining the most approximate knowledge of this effect on all the farm area. These authors confirmed that inclusion of heterogeneity of excretions had low effect on estimation of greenhouse gases emission model, when the grassland received less than 150 kg/ha/year of N.

Cárdenas *et al.* (2010) developed a model to determine N_2O emissions in fertilized grasslands, which can be used to widen limited information regarding flows of this gas in these ecosystems. These authors found a non linear response of the emissions of this gas with the applied doses of N fertilizer, and found emissions of N_2O that varied from 0.5 to 3.9 kg /ha/year of N.

As it was previously stated, several models have been developed in animal husbandry, which contain very valuable aspects for directing system functioning, like litter effect, radicular system, space distribution of animal excretions, volatilization of greenhouse gases, nitrate lixiviation and others. However, there are few models that contain the interrelation among the three main components of cattle rearing systems (soil-plant-animal)

At a global level, assessments have been carried out on the importance of modeling in grassland ecosystems (Thornley 2001), and ecological and socio-economical models have been proposed for producers to make decisions, in order to obtain more productivity in their farms (Hollman 2001 and Pérez-Quezada *et al.* 2011).

Ortiz (2000) developed RECICLAJE model, using data from a wide series of studies performed at the Animal Science Institute in Cuba (1999), and some other studies carried out in the same country. This model allows, through a dynamic program, to estimate the balance state of N, P and K in different systems of animal production. Analysis, design and implementation of the model, besides considering the requirements defined previously on specifications of a simulation model, foresees, with its application, the beginning of new studies on nutrient recycling, using the same program as a tool. This will allow the development and improvement of knowledge established on this subject and, at the same time, will achieve a higher fixing of the model to the particularities of each cattle rearing units in which it is applied.

Rodríguez *et al.* (2008) validated this model on commercial cattle production with favorable results in many cattle rearing units, mainly dairy farms, from the occidental region of Cuba.

CONCLUSIONS

Soil organisms (micro, meso and macrofauna) participate directly on organic matter decomposition, which allows the release of nutrients that take part of the biological, geological and chemical cycle of different ecosystems. Likewise, grassland litter is considered as the most important source of nutrient recycling in permanent grasslands, depending on grass species, climate and biological activity of soil.

Although the largest amount of nutrients recycled in grasslands is produced by animal excretions, their distribution in the ecosystem is very irregular and has low efficiency.

Root phytomass of grasses is another important source of nutrients recycled in grasslands, mainly within the first 10 cm of the soil.

Currently, researches on modeling different ways of recycling nutrients in permanent grasslands are being developed more efficiently, although RECICLAJE model, developed in Cuba, has demonstrated to be valuable for controlling the state of N, P and K balance per year in cattle rearing farms.

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