Functions of the soil organisms in the grassland ecosystem

G. Crespo
Instituto de Ciencia Animal, Apartado Postal 24, San José de las Lajas, Mayabeque, Cuba
Email: gcrespo@ica.co.cu

An update in the progress of the scientific researches related to the functions of the soil organisms in the grassland ecosystem is shown. The performance of different microorganisms in this ecosystem is recognized, focusing, mainly, on the functions of primary decomposers, like beetles, worms and termites. It is emphasized that these organisms, responsible for decomposing the excretions of mammals and the litter of the grasslands, increase the general fertility of soils and grassland productivity. The interactions between the primary decomposers and the microorganisms, which live in their gastrointestinal track and in the soil, are determinant in the functioning of this ecosystem. Worms, beetles, and termites have an important function in recycling nutrients in ecosystems of well-managed grasslands.

Key words: *organisms, soil, grassland, interactions*.

INTRODUCTION

The soil stores a large amount of organisms, from insects and worms to microscopic fungi and bacteria. These organisms work for the farmer, therefore they are considered of great importance (Coleman *et al*.2004).

It has been recognized that worms are good indicators for soil health (Panigrahi 2009). Studies have also confirmed that the forage production almost doubles when worms are introduced in the grasslands because of the important changes in the properties of the soil. Even more, there is a high correlation between the worm population and the forage production (Curry and Schmidt 2007).

Besides the worms there are also other species of visible organisms of the soil. There are, among them, the coprophagous beetles, the ladybirds (Isopods), the millipedes (Millipedes), the centipedes (Centipedes), the slugs (Mollusks), the snails (Basommatophora) and the springtails (Collembola), which are the primary decomposers (Coleman *et al*. 2004). They start eating the biggest particles of the plant residue and put them in contact with other organisms that decompose them later.

Although for a long time the function of termites in the decomposing of litter has been recognized, there is no much information about its importance in the decomposing of excretes, especially in herbivorous. Published studies show that there are different groups (at least 126 species) that feed from excretes of around18 species of mammals (Freymann *et al*. 2008).

In some cases 1 hectare of living soil can contain 1011 kg of worms, 1090 kg of fungi, 682 kg of bacteria, 60.5 kg of protozoa, 404.5 kg of arthropods, algae and other small mammals (Brown and Doube 2004). The understanding of the biological cycle of these organisms will allow making an efficient management of the grassland to optimize the biological activity.

All these organisms – from the microscopic bacteria to the great worms and snails—work together in the general ecosystem of the soil (Curry 1994). Because the human being cannot see most of them, it is common to forget them. However, they are present in the biologically active soils and intervene in many useful functions when the grasslands are efficiently managed.

The objective of this review is to show an update in the progress of the scientific researches related to the functions of the soil organisms in the grassland ecosystem, with a special approach to the coleopterans, worms and termites, which are the primary decomposers in recycling nutrients for these ecosystems.

FUNCTIONS OF INSECTS FROM SCARABAEIDAE GENRE

Insects from Coleoptera (Scarabaeidae) genre appear all over the world, frequently in different areas like low lands, alpine zones and even deserts. The biology and ecology of the group is so diverse that only few generalizations can be made (Stebnicka 2001). The common name of "dung beetles" refers to the taxon of this sub-family, which is frequently recollected in the dung of mammals.

The two main sources of food for Coleoptera are the excretions of omnivorous and the poor vegetation. The species may be divided into 2 groups: saprophagous and coprophagous (Nichols *et al*. 2008).

The saprophagous feed on dead or decomposing plant material, including leaf litter, decomposing fruits and flowers, compost, cut grasses and others. They are distributed around the world according to factors like type of vegetation and its state of decomposition, amount of free water in the soil, climate and other conditions. According to Stebnicka (2001) the "strong saprophagous" use hard organic substances, like dead wood, foliar leave litter and spores, while the "weak saprophagous" use the liquid and semi-liquid contents of decomposing vegetation, for instance, plant juice, solved albuminoidal substances and the albumin of decomposing humus.

Likewise, coprophagous feed from various fractions of excretion, and they are found in almost every type of them. The highest herbivorous eat great amounts of grass and some of this grass go through the digestive system without being digested. Besides, the excretion contains various digestive juices, albumin, fat, carbohydrates, mineral salts, vitamins, and traces of other substances, which include the bacterial albumin. Femails lay, as average, 20-25 eggs and most of the species have 2 generations per year. However, the emergence of its eggs is very variable and irregular, because the annual number of generations, in a determined area, depends on the climate and on the duration of the growth season (Stebnicka 2001).

Davis (1996) demonstrated that there is a high activity of coprophagous beetles and a fast decomposition of the excretions during the hot and rainy season of the year in Africa. However, a marked variation according to the type of soil was confirmed. Like that, a low incidence of these insects and lower rates of decomposition of excretions occurred in the loamy soils, compared to the lighter soils. This author also demonstrated the existence of positive correlations between the biomass of these coleopterans and the rate of decomposition in sandy soils. These studies facilitated the selection of future species of Coleoptera in order to optimize the decomposition of the excretions in the grasslands agroecosystems from Australia. Rodríguez *et al.* (2002) found a similar effect of the type of soil in the activity of coleopterans in Cuban grasslands.

According to Nichols *et al*. (2008), more knowledge about the relations between the ecological functions and the biodiversity is needed in order to predict the real consequences of the human activities in the environment. The coprophagous beetles from the Scarabaeinae subfamily provide several key functions of the ecosystem, which consume animal excretions, either adults or larvae. Through the management of excretions during the feeding process, these beetles produce vital functions in the ecosystem, like seed spreading, nutrients recycling and parasite suppression. Many of these ecological functions provided valuable services to the ecosystem, like diseases control and soil fertilization.

FUNCTIONS OF WORMS (OLIGOCHAETAS)

Taxonomically, worms belong to phylum Annelida, Oligochaeta class and Opisthophora order. This order is composed by 5 big families: Moniligastridae, Megascolidae, Eudrilidae, Glossoscolecidae and Lumbricidae. Worms have a significant function in improving the fertility of soils. Researchers have identified and named more than 4400 species of worms, its physical, biological and behavior characteristics that differentiate one to the other. The trophic classification divides them into 3 categories: phytophagous, phytogeophagous and geophagous, while other researchers divide them into epigeous, anecics and and endogeics (Panigrahi 2009).

Epigeous species, represented by *Perionyx excavates* (Eastern), *Eisenia foetida* (European) and *Eudrilus euginiae* (African), live on the soil and feed on animal and plant decomposition (Curry and Schmidt 2007). These worms build permanent tunnels and prefer the shallow layer of soil which is rich in organic matter, specifically the litter layer. In nature worms are better found in the leaves and organic remains than in the soil. These epigeous species are used in the vermicompost and compost practices around the world. They are identified as phytophagous and humus shapers.

Phytophagous are anecic species represented by *Lampito mauritii* (Eastern) and *Lumbricus terrestris*. They live in the first six inches of the soil and feed on organic matter that exists in the surface. These worms build vertical and permanent tunnels, which go from the surface to the mineral layer, which can happen from 4 to 6 feet deep (108 to 162 cm). They feed on decomposing organic matter, which they turn into humus (Lavelle and Spain 2001).

On the other hand, the endogeics are geophagous. Some species, like *Metaphire posthuma*, *Pheretima elongate*, *Octochaetona serrata* and *O. thurstoni*, are big worms that usually reach 1m or more of length. They live deep in the soil and feed on mineral soil only which, by chance, is also rich in organic matter. These worms go to the surface only during rainy season to deposit their large excretions (Panigrahi 2009).

These three trophic categories of worms have important functions in the management of soil fertility. This contribution is made through their fecal materials and their body secretions.

The formation of galleries by the worms favors the infiltration of water and air into the soil (Bouché 1977). They digest soil, organic material and microorganisms while they remove the soil. This process increases considerably the content of soluble nutrients.

Worms consume dead plant material and redistribute the organic material and plant nutrients through the soil profile. The research demonstrates that only a thin and superficial layer of organic material remains over the surface in the grasslands without worms (Brown *et al.* 2000). Worms also secret a material that stimulates plant growth and improves the quality of the soil. Besides, they reduce the transmission of parasitic nematodes in cow excretions (Brown and Doube 2004).

They prefer a neutral pH, humid soil and enough plants remains in the surface, and they are sensitive to some pesticides. The fertilizers applied over the surface of the soil are usually beneficial, but the anhydrous ammonium kills them and plowing destroys the galleries (Curry and Schmidt 2007). The efforts to protect the increase of the worm population will produce more productive and healthy grasslands.

The gastrointestinal track of worms acts like a "bioreactor" where, under ideal conditions of temperature, humidity and pH, beneficial breeds of aerobic bacteria multiply (Drake and Horn 2007).

There is an increasing appreciation of synergic interactions between worms and microorganisms. The main interest is focused on the ingestion of soil microorganisms and their movement through the intestine (Egert *et al*. 2004, Parthasarathi *et al*. 2007, Byzoy *et al*. 2009and Thakuria *et al*. 2009). Some researchers demonstrate that microbes inside a worm intestine are associated to a microbial profile of soil and the food sources (McLean *et al.*, 2006, Drake & Horn, 2007, Knapp *et al*. 2008 and Jayasinghe *et al*. 2009). The small differences in the bacteria community among the soil, the worm intestine and the fresh excretions in *L. terrestris* indicate that it is not possible the existence of a native microbial community inside the worm (Egert *et al*. 2004).

Knapp (2009) informed similar results although other studies have shown the existence of symbionts within the worm intestine (Sampedro 2007). Other researches state that some microorganisms present in the intestine of these animals were not in the soil (Byzoy *et al*. 2009). The presence of all bacteria in the gastrointestinal track of the worm and in the soil does not allow determining if the bacteria community has a mutualistically metabolic or symbiotic interaction with it (Thakuria *et al*. 2010).

Further studies are needed, in a more diverse amount of worm species, to confirm the actual presence of symbionts in the gastrointestinal system and its functions. In fact, the net contribution of worms in the soil fertility comes from the biomass of fungi and bacteria they excrete. The worm concentration in a soil indicates the presence of a beneficial biomass of fungi and bacteria. It also suggests that the soil does not need much care regarding its fertility (Byzov *et al*. 2009).

Worms are voracious consumers of food. According to the estimated daily consumption of food per a thousand kilograms of live weight, the elephants consume around 4 kg, men around 20 kg, mice around 200 kg, worms around 500, fungi two thousand kilograms and bacteria twenty thousand kilograms. This fact turns bacteria into the super consumer of food in the animal kingdom (Panigrahi 2009).

Although some species of worms spread in the sub-soil to avoid dryness, the most common of them remain in the dry layer of the soil, were they can stand losses up to ¾ of the water content. On the other hand, the long flooding periods cause death to these organisms, but they can tolerate short periods of flooding and a great number of them is found under the irrigated grasslands (Barley 1964). In Cuba, Lok and Fraga (2008) have found more biomass of worms in the grasslands, with a predominance of a multiple mixture of perennial legumes and silvopastoral systems.

FUNCTIONS OF TERMITES (ISOPTERA)

Although for a long time the important function of termites in decomposing litter has been recognized, there is no much information about its importance in decomposing excretes, especially in herbivorous. Published studies show that there are different groups (at least 126 species) that feed from excretes from at least 18 species of mammals (Freymann *et al*. 2008).

These species that feed on wood remains and on the phytophagous of litter from timber wood trees are more frequently found in the excretions (Bignell and Eggleton 2000). Even more, studies have discovered that termites can decompose great amounts of mammal excretions preferably during the dry season, indicating values of 1/3 of the excretions removed by these organisms in only 1 month, mainly in native grasslands (Ferrar and Watson 1970). On the other hand, no preferences between the mammal excretions and other types of organic sources have been observed. Although termites add great amounts of excretions in the soil and increase the number of nutrients of it, this has been rejected as a process of great importance in the functioning of tropical ecosystems. There is information about the excrete disintegration activity of termites in Africa, Asia, Australia and America (North, center and South).

There are no references related to the termite species that feed on the excretions of only one mammal specie. Results indicate that the species that mainly feed on wood (42 species = 39%) and on litter of timber wood trees (27 = 25%) also feed on mammal excretes, which is very important (Freymann *et al*. 2008).

According to Higashi *et al*. (1992), termites generally feed on dead plant materials that has a C/N relation higher than their own tissues and has to balance their entries of C and N. In this sense, Quédraogo *et al*. (2004) compared the C/N relation in several food provided to termites, like Andropogon straws (153 and 0.32% of N), cow excretions (40 and 0.95% of N) and corn wastes (59 and 0.77% of N). The cow excretions provided termites with a more favorable C/N relation and it was more attractive to these organisms. In spite of the great content of phosphorus in this excretes (1.06% vs. 0.03% in the straw of Andropogon and 0.18% in the corn waste), the macrofauna of soil preferred to decompose the fibrous materials. This means that the available opportunities for termites to compensate food of very low quality simply break the rules of high selectiveness in terms of the C/N relation of food.

Compared to the litter, excretions appear in the field and are locally available as accumulations of leaf litter and organic matter, added by big herbivorous. Termites could benefit themselves with energy when exploring excretions with a major mass per volume, instead of feeding on litter, which has to be collected in a wide space range and a less favorable microclimate. Even more, mammals and their endosymbionts fragment and preprocess biochemically plant materials and, in this way, help the termites to use them later (Dangerfield and Schuurman 2000).

The excretions, naturally deposited in the soil by mammals, needs to be decomposed and incorporated in the soil as part of the recycling of nutrients. Adamson (1943) suggested that termites have an important part in keeping fertility of soils and productivity of ecosystems. Besides, termites help with the entrance of air, drainage and penetration of roots, and contribute to the development of soil thanks to their epigeous style of life. They also accelerate the formation of humus and the recycling of mineral elements when consuming dead woods and other plant remains.

According to Quédraogo *et al*. (2004), termites can decompose from 12 to 57% of the excretions in only 1 month. These authors found higher rates of decomposition during the dry season than in the rainy season. Per month, these rates were of 12 % in the desert, from 36 to 57 % in the savannas, 31 % in agricultural fields and 12 % in the grasslands. An average value of 30 %/month of excrete decomposition of termites can be estimated.

Some authors, like Whitehead (1986), point that coprophagous beetles are the highest responsible for the disintegration of excretions during the rainy season. However, during the dry season, the work of termites is more important.

There are enough evidences to state that termites affect the functioning of the ecosystem through the recycling of nutrients. Coe (1977) estimated that in the National Park of Kenya, termites remove up to 8.7 X 10^3 kg of excretes/km^2 every year in the grasslands. This represents a release of around 12 kg/ha/year and offers an idea of the function of termites in facilitating the return of nutrients to the soil during the recycling process.

Regarding the general recycling of nutrients, termites can be seen as an important connection between the excretions of mammals and microbial decomposers for the next fragmentations in native grasslands. They can be even more important due to the redistribution they do to the particles of excretions.

In Costa Rica, studies have indicated that termites are the most important excrete decomposers insects in the grasslands of that country (Gould *et al*. 2001).

OTHER ORGANISMS OF INTEREST IN THE GRASSLAND ECOSYSTEM

Bacteria are considered to be the most numerous organisms in the soils. Therefore, 1 g of soil can contain, at least, 1 million of these unicellular organisms (Torsvik and Ovreas 2002). One of the major benefits of bacteria is to help plants to take nutrients and the first way to do it is through the release of nutrients from the organic matter and from the mineral of soil.

Although the actinomycetes are not as numerous as bacteria, they have important functions in the soil. Like bacteria, they help to turn organic material into humus, with the release of nutrients and production of antibiotics that eliminates diseases from the roots (Lavelle and Spain 2001).

Fungi are present in different sizes within the soil. Some species form colonies while others are unicellular yeasts. Mycorrhizas are fungi that live over or in the plant root and act to extend the root hairs inside the soil. They increase the taking of water and nutrients, especially in the soils with a lack of nutrients, and, in return, fungi benefit by absorbing nutrients and carbohydrates from the roots where they live (Lavelle *et al*. 1995).

Many species of algae also live in the soil. These organisms produce their own food through the photosynthesis process. They appear as a green thin layer over the soil surface the rains. Their first function is to improve the structure of the soil through the production of materials that agglutinate particles together with the stable aggregates of water. Besides, some species (like the green-blue) can fix N, which is later released and absorbed by the plant roots (Bohlen and Gathumbi 2007).

Protozoa are animals that live free, swimming in the water among the particles of soil, while others live in the gastrointestinal track of earth worms (Cai H. *et al*. 2002). Many of their species eat other microorganisms and, when consuming bacteria, contribute to the release of N and other nutrients through their excretions.

Nematodes are abundant in most of soils and only few species are harmful for plants. The majority of these species eat plant litter, bacteria, fungi, algae, protozoa and other nematodes. Like other predators, nematodes influence on the rate of nutrient recycling (Bardgett, *et al*. 1999).

CONCLUSIONS

The presence of beetles is reported around the world. The saprophagous feed on decomposing and dead plant materials while coprophagous feed on different fractions of excretions from almost all types of animals.

Worms consume dead plant material and redistribute the organic matter and plant nutrients in the soil profile. They create galleries in the soil, favoring the infiltration of water and air.

The important functions of termites in the decomposition of grassland litter are recognized, although recent studies discovered that these organisms also feed on the excretions of many species of mammals and decompose them mainly during dry periods.

The previous soil organisms, considered as primary consumers, have a close interaction with bacteria, actinomycetes, fungi, blue-green algae, protozoa and nematodes in the efficient recycling of nutrients in the ecosystems of tropical grasslands.

REFERENCES

Adamson, A.M. 1943. Termites and the fertility of soils. Trop. Agric. 20:107

Bardgett, R.D., Cook, R., Yeates, G.W. & Denton, C.S. 1999. The influence of nematodes on below-ground processes in grassland ecosystems. Plant Soil 212:23

Barley, K.P. 1964. Earthworms and the decay of plan litter and dung – A Review. Proc. Aust. Soc. Anim. Prod. 5:236

Bignell, D.E. & Eggleton, P. 2000. Termites in ecosystems. In: Abe, T., Bignell, D.E. & Higashi, M. (Eds).Termites: Evolution, Sociality, Symbioses, Ecology. Kluwer Academic Publications. Dordrecht. p. 363

Bohlen, P.J. & Gathumbi, S.M. 2007. Nitrogen cycling in Seasonal Wetlands in Subtropical Cattle Pastures. Soil Sci. Soc. America J. 71 : 1058

Bouché, M.B. 1977. Stratégies lombriciennes. In : Persson, T. & Lohm U. (Eds.) Soil organism as components of ecosystems. Proc. 6th International soil zoology colloquium, Uppsala. Ecol. Bulletins 25 :122

Brown, G.G., Barois, I. & Lavelle, P. 2000. Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. Eur. J. Soil Biol. 36 : 177

Brown, G.G. & Doube, B.M. 2004. Functional interactions between earthworms, microorganisms, organic matter, and plants. In : Edwards, C.A. (Eds.) Earthworm ecology. Boca Raton, FL, USA: CRC Press LLC.Pp.213-239

Byzov, B.A., Nechitaylo, T.Y., Bumazhkin, B.K., Kurakov, A.V. & Golyshin, P.N. 2009. Culturable microorgansims from the earthworm digestive tract. Microbiol. 78:360

Cai, H. & John, P.F. 2002. Fate of protozoa transiting the digestive tract of the earthworm *Lumbricus terrestris* L. Pedobiologia 46:161

Coe, M. 1977. The role of termites in the removal of elephant dung in the Tsavo (East) National Park Kenya. E. Afr. Wildl. J. 15: 49

Coleman, D.C., Crossley D.A.J. & Hendrix, P.F., 2004. Fundamentals of soil ecology. Amsterdam. The Netherlands. Boston, MA, USA: Elsevier Academic Press.

Curry, J. P. 1994. Grassland Invertebrates: Ecology, Influence on Soil Fertility, and Effects on Plant Growth. 437 pp.

Curry, J.P. & Schmidt O. 2007. The feeding ecology of earthworms - A review. Pedobiologia 50:463

Dangerfield, J.M. & Schuurman, G. 2000. Foraging by fungusgrowing termites (Isoptera: Termitidae, Macrotermitinae) in the Okavango Delta, Botswana. J. Trop. Ecol. 16:717

Davis, A.L.V. 1996. Seasonal dung beetle activity and dung dispersal in selected South African habitats: implications for pasture improvement in Australia. Agric. Ecosystems & Environment 58: 157

Drake, H.L. & Horn, M.A. 2007. As the worm turns: the earthworm gut as a transient habitat for soil microbial biomes. Ann. Rev. Microbiol. 61:169

Egert, M., Marhan, S., Wagner, B. & Scheu, S. 2004. Molecular profiling of 16S rRNA genes reveals diet-related ... of microbial communities in soil, gut, and casts of *Lumbricus terrestris* L. (Oligochaeta: Lumbricidae). FEMS. Microbiol. Ecol. 48:187

Ferrar, P. & Watson, J.A.L. 1970. Termites (Isoptera) associated with dung in Australia. J. Aust. Entomol. Soc. 9:100

Freymann, B.P., Buitenwerf, R., Desouza, Og. & HanOlf, 2008. The importance of termites (Isoptera) for the recycling of herbivore dung in tropical ecosystems: a review. Eur. J. Entomol. 105:165

Gould, H., Herrik, J. & Lezama, H. 2001. Refuse to Refuge: Dry Season Use and Modification of Cattle Dung by Subterranean Termites in Guanacaste, Costa Rica. Biotropica 33:121

Haynes, R.J. & Williams, P.H. 1993. Nutrient cycling and soil fertility in the grazed pasture ecosystem. Advances in Agronomy 49:119

Higashi, M., Abe. T. & Burns, T.P. 1992: Carbon-nitrogen balance and termite ecology. Proc. R. Soc. Lond. (B) 249:303

Jayasinghe, B.A. & Parkinson, D. 2009. Earthworms as the vectors of actinomycetes antagonistic to litter decomposer fungi. Appl. Soil Ecol. 43:1

Knapp, B.A., Seeber, J., Podmirseg, S.M., Meyer, E. & Insam, H. 2008. Application of denaturing gradient gel electrophoresis for analysing the gut microflora of Lumbricus rubellus Hoffmeister under different feeding conditions. Entomol. Res. 98:271

Knapp, B.A., Podmirseg, S.M., Seeber, J., Meyer, E. & Insam, H. 2009. Diet-related composition of the gut microbiota of Lumbricus rubellus as revealed by a molecular. Soil Biol. Biochem. 41:2299

Lavelle, P., Lattaud C., Trigo, D. & Barois I. 1995. Mutualism and biodiversity in soils. Plant Soil 170:23

Lavelle P. & Spain A.V. 2001. Soil ecology. London: Chapman and Hall.

Lok, S. & Fraga, S. 2008. Methodology for the selection of sustainability indicators of the soil-plant system in grasslands. Cuban J. Agric. Sci. 42:69

McLean, M.A., Migge-Kleian, S. & Parkinson, D. 2006. Earthworm invasions of ecosystems devoid of earthworms: effect on soil microbes. Biol. Invasions 8:1257

Nichols, E., Spector, S., Louzada, J., Larsen, T., Amezquita, S. & Favila, M.E. 2008. Ecological functions and ecosystem services provided by Scarabaeinae dung beetles. Biol. Conservation 141:1461

Panigrahi, A.K. 2009. Earthworms and their role in soil fertility enhancement. Available: http://www.articlesbase.com/environment-articles/earthworms-and-their-role-in-soil-fertility-enhancement-1054001.html. [Consulted: 12 de agosto 2012]

Parthasarathi, K., Ranganathan L.S., Anandi V. & Zeyer J. 2007. Diversity of microflora in the gut and casts of tropical composting earthworms reared on different substrates. J. Environ. Biol. 28:87

Quédraogo, E., Mando, E. & Brussaard, L. 2004. Soil macrofaunal-mediated organic resource disappearance in semi-arid West Africa. Appl. Soil Ecol. 27:259

Sampedro, H.L. 2007. Microscale interaction between earthworms and microorganisms. Microbiology 78 : 369

Stebnicka, Z. T. 2001. Aphodiinae (Insecta: Coleoptera: Scarabaeidae). Fauna of New Zealand 42:64

Rodríguez, I., Torres, V., Crespo, G. & Fraga, S. 2002. Biomass and diversity of the soil macrofauna in different grasslands. Cuban J. Agric. Sci. 36:389

Thakuria, D., Schmidt, O., LIliensiek, A.K., Egan, D. and Doohan, F.M. 2009. Field preservation and DNA extraction methods for intestinal microbial diversity analysis in earthworms. Journal of Microbiological Methods 76:226

Thakuria, D., Schmidt, O., Finan, D., Egan, D & Doohan, F.M. 2010. Gut wall bacteria of earthworms: a natural selection process. Torsvik, V. & Ovreas L. 2002. Microbial diversity and function in soil: from genes to ecosystems. Curr. Opin. Microbiol. 5:240

Whithead, D.C. 1986. Sources and transformation of organic nitrogen in intensively managed grassland soils. In: Meer van der, Ryden, J.C y Ennik G.C. (Eds.). Nitrogen fluxes in intensive grassland systems. Pp. 47-58

Received: January 16, 2013