...opical Forage Species: Their Contribution to Nutrient Recycling in Savanna Ecosystems

In 1882, H Joulie wrote "It is preferable to alternate the cultivation of roots and cereals with that of grass leys so as to repair by the second the loss of nitrogen which the first cause to the soil By this means, cultivation can be kept up indefinitely without purchased nitrogen." This statement is as valid today as it was over one hundred years ago

In natural ecosystems, especially those of tropical forests, nutrient recycling is usually very efficient. Nutrient losses are balanced by the addition of elements from the atmosphere and weathering of the soil s parental material. Conversely, in agricultural systems, the cycle is altered by the removal of nutrients by plant products, leaching, and soil erosion. Losses are smaller in pastures, hence their use in maintaining soil fertility, as well as for their productive function

Since 1989, CIAT s Tropical Pastures scientists Richard Thomas, Miguel Ayarza, and their colleagues, have been studying nutrient recycling in pastures at the Colombian national research center at Carimagua The scientists are characterizing some of the biotic and abiotic components of this process in pastures tolerant of soil acidity

Pastures and nutrient recycling

Pasture researchers have demonstrated that grazing animals remove fewer nutrients from the soil than do crops Animals retain only a small proportion, about 20%, of the nutrients that they ingest, and the rest is returned to the soil through excreta However, it has been established that some of those nutrients, especially nitrogen and potassium, can be lost from the excreta through volatilization and/or leaching at rates according to environmental conditions These concepts and their application to nutrient recycling in tropical savannas are illustrated in Figure 1

Figure 2 simulates nitrogen recycling in a *Brachiaria dictyoneura*-*Arachis pintoi* pasture that produces 22 t/ha of dry matter annually In this example, the grazing animal consumes 126 kg of N, of which it utilizes 13 kg to increase its weight, the rest is excreted in feces and urine, although a large proportion can be volatilized, denitrified, or immobilized in organic matter and thus cannot be re-used by plants In this example, legumes partly recover these losses through biological nitrogen fixation so that the soil organic matter has only to supply 5 kg of N to maintain the system s stability In the absence of forage legumes, that organic matter would have to supply approximately 149 kg of N (144 + 5) to balance the N cycle Obviously, this loss in soil reserves is not sustainable over the long term

The 57 kg of N entering the system as stable organic matter represent the pasture s capacity to accumulate this nutrient (Figure 2) It is not usable in the short term unless the soil is disturbed mechanically, for instance, in planting upland rice

Differences between grasses and legumes

Tropical grasses and legumes differ in their photosynthetic activity Grasses are type C_4 plants and fix carbon by the Hatch-Slack cycle, whereas legumes are type C_3 plants and utilize the Calvin cycle to fix carbon These differences modify carbon isotope ratios (that is, ^{13}C to ^{12}C ratio) in plant tissues, which makes it possible to distinguish their respective contributions to the soil organic matter By using this ratio, it was demonstrated that, in a ten-year-old Brachiaria decumbens-Pueraria phaseoloides pasture at Carimagua, the legume contributed about 17/ to the organic carbon found in the top 10 cm of the soil Such a contribution to the system was associated with a yield increase of 1 7 t/ha in a rice crop that was subsequently planted in the same field, with no nitrogen application In contrast, the yields of a rice crop planted after Brachiaria alone were not as high

There is also a big difference in the decomposition of plant litter between grasses and legumes Compared with grasses, legumes release more nitrogen, and have wider ranges of nutrient release patterns over time than grasses (Photo 1) For example, at Carimagua, Stylosanthes capitata released nitrogen faster than Desmodium ovalifolium (Figure 3). This characteristic makes it possible to synchronize the supply of nutrients from litter with the demand from crops, and to exploit this process in developing management systems for different agroecosystems

Phosphorus recycling

A shortage of phosphorus is the most limiting factor for agricultural production in acid soils, which are characterized by mineral fixation in the soil and immobilization of elements by microorganisms However, plant species tolerant of soil acidity have developed root mechanisms that enable them to grow in phosphorus-deficient soils One of these mechanisms is the association with mycorrhizal fungi These fungi allow plants to explore larger volumes of soil in search of available phosphorus Most species selected by the Tropical Pastures Program for acid soils depend, to a large extent, on this mechanism to assimilate soil phosphorus

Another mechanism, found especially in legumes, is the excretion of phosphatases and other exudates by roots In the field, this mechanism allows forage species to dissolve organic phosphorus found in plant and animal residues already incorporated into soil organic matter, thus improving nutrient recycling The importance of improved pastures for organic P accumulation is shown in Figure 4. In an Oxisol of Carimagua, Colombia, the organic P pool increased by 20% in the presence of A gayanus/C acutifolium, in comparison with native savanna

Roots and nutrient recycling

Another mechanism of acid-soil tolerant pastures to maximize nutrient recycling is the production of roots close to the soil surface (Photo 2), a characteristic which was observed in a B decumbens-A. pintoi pasture which had been grazed for five years (Figure 5) Most roots of this association were found in the top 10 cm of the soil, although some were found at one meter This mechanism is important for nutrient conservation because the distance between the site where nutrients are released by organic matter and the site where they are absorbed by the plant is very short Therefore, they are not leached before being used by the plant

Besides absorbing nutrients, roots are an important source of carbon for soil microorganisms and contribute to the formation of organic matter The quantity and quality of organic matter in improved pastures depend on root biomass and rate of renewal Both parameters are influenced by soil fertility and grazing management

Prospects

The return of plant residues to the soil is the most important process in nutrient recycling for pastures established on tropical savannas. This process can be partly controlled through selection of forage species and grazing management Grass-legume pastures are efficient in the use and conservation of resources, as they can maintain soil fertility via the recycling of nutrients This gives pastures advantages over crops

The Tropical Pastures Program has begun an ambitious interdisciplinary research project designed to evaluate, among other factors, different ways of managing the soil-plant-animal relationships and their effects on nutrient recycling

Together with the Program s research on the adaptation of forage species to acid soils (page XX), these efforts reaffirm CIAT s strategy for the nineties, that of appropriately managing natural resources for their conservation and adequate exploitation

Photo legends

Photo 1. Decomposition of plant litter plays an important role in nutrient recycling in tropical pastures

Photo 2 Root system in a rice-pasture association, Carimagua, Colombia

Figure 1 Basic concepts of nutrient recycling in tropical savannas

Inputs	Recycling	Outputs	
Mineral supplements	Animal	Meat	Milk
	Plants	Herbage	
Fertilizer	Soil	Leaching	
Atmospheric rain and dust		Erosion	
		Gaseous losses	

Figure 2 Annual nitrogen cycle in a *Brachiaria decumbens*-*Arachis pintoi* pasture, Carimagua, Colombia (DM = dry matter, LWG = liveweight gain, OM = organic matter)

DM (t/ha) = 16 (grass) + 6 (legume) = 22

N (kg/ha) = 156 + 160 = 316

Utilization = 40%

Plant biomass 316 Legume 160 x 0 9 = 144

Fixed N Internal recycling Plant litter 95

Uptake by plant Leaching Denitrification

Soil inorganic N

Fertilizer Excretion Loss of soil OM -5

N obtained from excreta 34 Soil OM

Stable 57 Active 38

Feces N lost from excreta 79 Animal biomass 13

LWG/ha (2 5% N) 504

Animal intake 126

Amount of N recycled (kg)

Excreta = 34

Litter = 38

Removed = 95

N_2 fixed = 144

Total = 311

To soil = 316 - 311 = 5

Figure 3 Nitrogen loss over time in tropical grasses and legumes A = N lost from legume litter, B = N lost from grass litter

N (mg/pot) 0 100 200 A B

Days 0 20 40 60 80 100 120 140

Days 0 20 40 60 80 100 120 140

<u>C</u> <u>a</u> = <u>Centrosema acutifolium</u>

<u>P</u> <u>p</u> = <u>Pueraria phaseoloides</u>

<u>A</u> <u>p</u> = <u>Arachis pintoi</u>

<u>D</u> <u>o</u> = <u>Desmodium ovalifolium</u>

<u>S</u> <u>g</u> = <u>Stylosanthes guianensis</u>

<u>S</u> <u>c</u> = <u>Stylosanthes capitata</u>

<u>A</u> <u>g</u> = <u>Andropogon gayanus</u>

<u>B</u> <u>d</u> = <u>Brachiaria dictyoneura</u>

<u>B</u> <u>h</u> = <u>Brachiaria humidicola</u>

Figure 4   Organic phosphorus in the top 5 cm of a medium-textured soil in which three pastures were established, Carimagua, Colombia (Numbers at the top of bars correspond to total soil P in ppm)

Soil organic P (/ of total)

0   5   10   15   20   25   30   35

Native savanna   A gayanus   A gayanus + C acutifolium

P_t 44 8 P_t 61 6 P_t 69 0

Figure 5   Root distribution in a Brachiaria decumbens-Arachis pintoi pasture growing on an Oxisol and grazed for five years, Carimagua, Colombia

Soil depth (cm)

0-10   10-20   20-30   30-40   40-50   50-60   60-70   70-80   80-90   90-100

Total roots (/)

0   5   10   15   20   25   30