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*Article*

# Agricultural Systems Located in the Forest-Savanna Ecotone of the Venezuelan Amazonian. Are Organic Agroforestry Farms Sustainable?

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**Abstract:** The savannas located in the forest-savanna ecotone in the Venezuelan Amazon have unfertile sandy ultisols and entisols which show a very low crop production unless they are supplemented with large amounts of fertiliser. In spite of this restriction, local farmers have established long-term production systems by using low input doses of organic manure. The use of organic waste in unfertile ultisols and entisols typical of savannas have resulted in increases in organic matter content and biological activities in soils with respect to inorganic fertilised or non-fertilised natural savanna, which, in turn, may be related to increases in crop productivity. These results could be a successful and reliable soil management technique for rehabilitation of the South American savannas.

**Keywords:** organic farms; soil quality; microbial biomass; enzymatic activities; Amazonia

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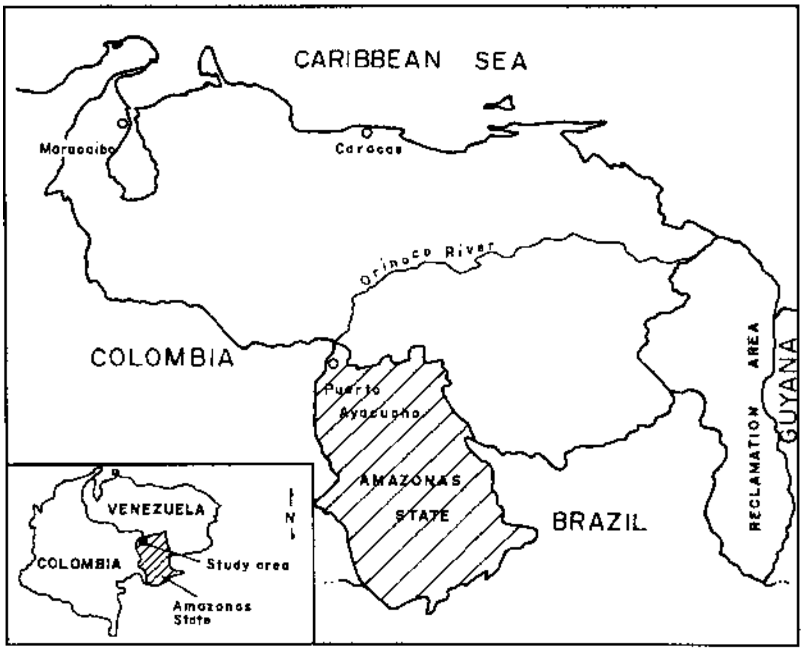
## 1. Introduction

Neotropical savannas represent, due to their extension, one of the last frontiers for agricultural expansion, therefore the savannas of the Brazilian Cerrado and the Llanos of Venezuela and Colombia have been under intensive agricultural activities after the introduction of commercial crops, improved grasses and agroforestry tree plantations in concerted government programs that started at least forty to fifty years ago [1-4]. Most of the farms and agricultural enterprises existing in those savannas are subject to inorganic fertilisation, with relatively few examples of long-term organic farm fertilisation, a situation that, on the contrary, is a common agriculture practice in the northern part of America and Europe [5].

The savannas located at the border of the Amazon forest around Puerto Ayacucho, Amazonas State, Venezuela (Figure 1), have ultisols and entisols developed under strong weathering induced by high temperatures and precipitation in that area. Soils are characterised by a low natural fertility and concomitantly low total C, N and P contents [6,7]. Consequently, intensive agricultural development in those savannas should be limited to the need to use large amounts of fertilisers (N and P). The soils, in the area, have also a very high sand content (> 93%), so, besides the low fertility, a poor water holding capacity also affects crop production.

**Figure 1.** Geographical location of the studied sites in savannas located near Puerto Ayacucho, Amazonas State, Venezuela.




Some local farmers in Venezuelan Amazonian have established in the savannas different agricultural systems by using low addition of inorganic and organic fertilisers [8]. The organic agricultural systems (**OS**) in this part of Venezuelan Amazonian appeared as a consequence of the inexistence of natural inorganic fertiliser sources nearby, and the expensive costs of using and transporting chemical fertilisers to an economically depleted area with a progressive elimination of government subsidies to agriculture [8]. Moreover, because of the sandy texture of soils the organic amendments are used to increase fertility and simultaneously improve soil structure [9]. Studies on the effects of organic amendments on fertility and crop production are abundant in the agronomical literature [5,10-12]. Those studies have demonstrated the influence of long-term manure application on the physical, chemical and biological properties of soils [5,13-15]. Since the biological components of soils respond more rapidly to changing soil conditions than do either physical or chemical properties, they may be regarded as sensitive indicators of soil conditions [16-20]. Studies assessing impacts of organic amendments and cover crops on soil quality in contrasting environments have focused primarily on C-related properties [5,21,22]. This fact is understandable, due to the important role that soil organic matter plays in maintaining soil productivity [5,23]; nonetheless according with recent trends in the analysis of soil quality [24,25], a comprehensive evaluation of multiple functions of soil require the assessment of soil physical, chemical, biochemical, and biological properties and processes. Impact of organic amendments on soil quality indicators have been thoroughly examined in temperate zones; however a lack of information exists for long-term organic amended sites in highly weathered tropical soils. Thus, small organic fertilised farms appeared as a potentially sustainable production system, poorly studied in the South American savannas and even in the whole Amazon. The **OSs** here analysed correspond to agricultural systems fertilised with a low rate of organic manure (about 2 Mg $ha^{-1}$), a relatively low input dressing, instead of the high input additions usually used in organic agriculture [26]. Therefore, information on those agricultural systems is valuable to choose specific management practices, which promote microbiological and biochemical activities in weathered soils where mineralisation of organic matter is an important supply of essential nutrients.

The objective of this contribution was to evaluate the long-term effect of low input of organic amendments on soil physical, chemical and biological properties in savannas near Puerto Ayacucho, Amazonas State, Venezuela. The results were compared to those obtained with soils from inorganically fertilised plots in the same savannas.

## 2. Materials and Methods

### *2.1. Site Description*

The **OSs** studied were located near the community of Provincial (Figure 2), 15 Km North of Puerto Ayacucho, Amazonas State, in the southern part of Venezuela (5°45' N; 67°33' W), whereas the inorganic plots (**IS**) were located in a *Trachypogon* savanna located at 5°27' N and 67°30' W, near Sabaneta de Guayabal, south of Puerto Ayacucho at 80 meters above sea level (Figure 2).

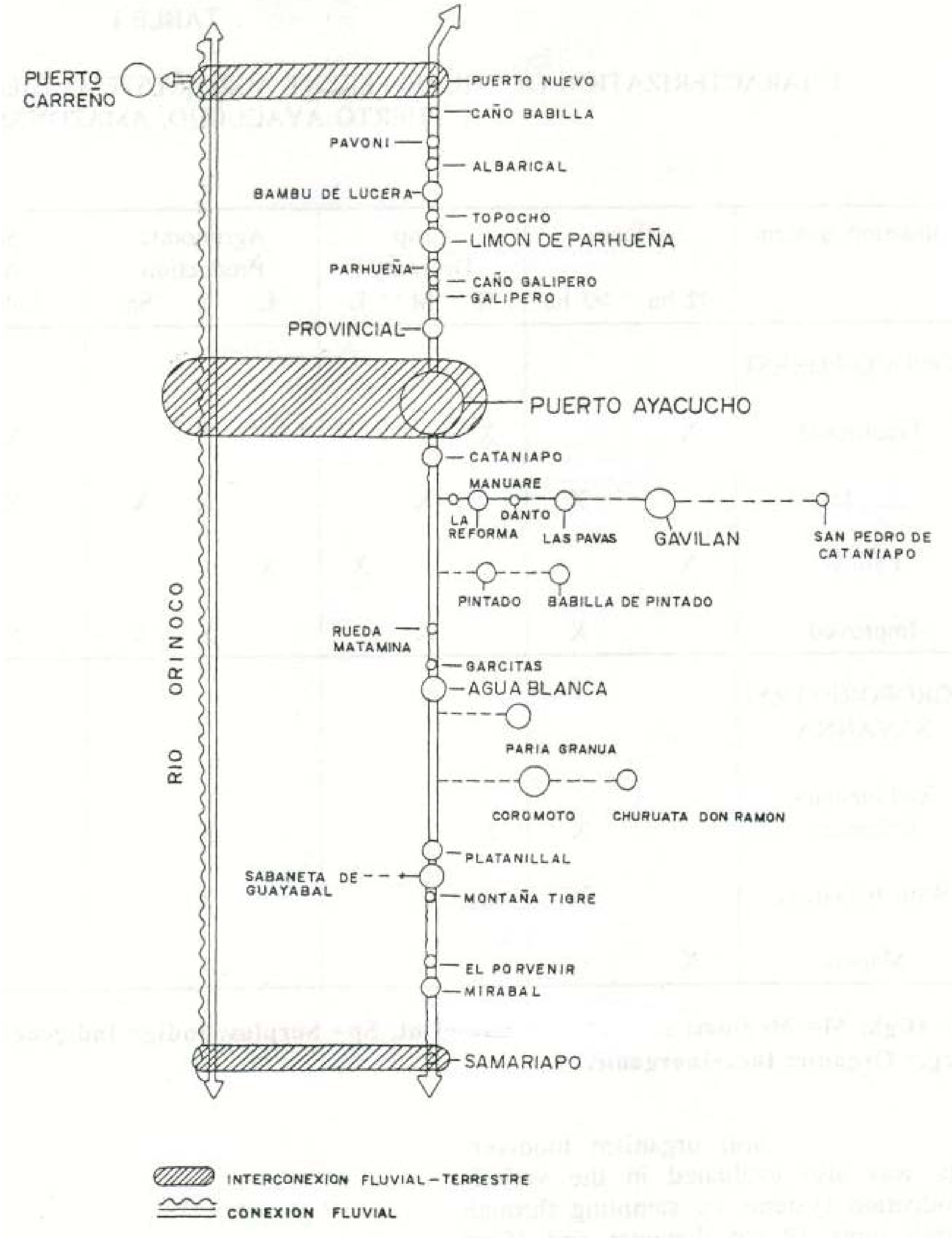
The region has a marked seasonality. The rainy season starts approximately in April and ends in November. The annual average temperature and precipitation are 26.5 °C and 2,338 mm, respectively. The soils of the study areas are Entisols (*Typic Ustipsamments*) and Ultisols (USDA) for the **OS** and **IS**, respectively. Both soils have natural low fertility, acidic pH and sandy texture (over 93%) that allows fast internal drainage. Consequently, those light textured soils may be very dry during the dry season.

### *2.2. Organic Agricultural Systems* (**OS**) *Assessed*

#### 2.2.1. Farm amended with cattle manure (**CM**)

The site corresponds to a Majada (cow-fold), the Majada is a fenced small piece of savanna land, cropped to annual plants and fruit trees, of less than 2 ha in size. Nutrients applied are derived from the excrement of cattle (mainly cows) which are confined in the site for several months; after that period, cows are carried out to another place to start a new Majada. Once the manure dries out, the planting of grains, fruit trees and vegetables crops starts. Therefore, in this agricultural system the rate of manure dressing is high (over 5-10 Mg $ha^{-1}$), depending on the extension of the plot and the size of the herd. Majada is a complementary production system, originated in the Llanos and practiced by criollos for self-consumption. This type of agricultural system can be found near the village of Provincial (Figure 2).

**Figure 2.** Location of the different agricultural systems (AS) studied in savannas near Puerto Ayacucho, Amazonas State, Venezuela.



2.2.2. Farm amended with chicken manure (**CHM**)

The soils sampled correspond to "Granja San José", a small fruit-tree farm of approximately 5 ha, which have been fertilised with chicken manure for over 30 years up to the present in a low input dressing (about 2 Mg $ha^{-1}$, Table 1); inorganic fertiliser has never been used. The farm is cultivated with local crops such as cassava (*Manihot esculenta*), and fruit trees like Musaceas, lemons (*Citrus* sp) and mangoes (*Manguifera indica*) planted in a non-organized manner. In addition to the fruit trees, crops such as chili pepper (*Capsium frutescens*) and beans (*Vigna unguiculata*) are also cultivated. No other specific management practices are applied besides the organic fertilisation.

**Table 1.** Management description of the organic and inorganic amended sites located near Puerto Ayacucho, Amazonas State, Venezuela.

| Agricultural Systems | Type of Plantation | Surface | Type of fertiliser | Time of addition | Dose of Manure | Irrigation |
|---|---|---|---|---|---|---|
| **Organic-CM** | Year crops | < 2 ha | Cattle | >1 yr | 10 Mg $ha^{-1}$ | No Irrigation |
| **Organic-CHM** | Agro-forestal | 5 ha | Chicken | 30 yr | 2 Mg $ha^{-1}$ | Manual Irrigation |
| **Organic-Comp** | Agro-forestal | 5 ha | Chicken Compost | 30 yr | 2 Mg $ha^{-1}$ | Sprinkles |
| **Organic-GM** | Yucca | < 2 ha | Green manure | >1 yr | Unknown | No Irrigation |
| **Inorganic- I 1** | Brachiaria | 20 ha | Inorganic | 1 year | Unknown | No Irrigation |
| **Inorganic-I 2** | Brachiaria, Leguminous | 0.4 ha | Inorganic | 2 years | 1 Mg $ha^{-1}$ phosphate rock, 0.3 Mg $ha^{-1}$ NPK | No Irrigation |

2.2.3. Farm amended with compost (**Comp**)

The farm "Granja Cachama", is a small fruit-tree farm of approximately 15 ha, where organic manures have been applied for over 30 years, firstly as chicken manure from 1970 to 1982 and then from 1982 to present as a compost made up from pig manure, rotten fruits, soil and plant debris in a low input dressing (about 2 Mg $ha^{-1}$) (Table 2).

**Table 2.** Soil physical parameters in control and organically amended plots (**OS**).

| **OS** | **CM** | | **CMH** | | **Comp** | |
|---|---|---|---|---|---|---|
| | **Control** | **Treatment** | **Control** | **Treatment** | **Control** | **Treatment** |
| Water retention capacity (%) | 6.44 a ± 0.4 | 9.75 b ± 0.5 | 7.99 a ± 0.4 | 8.98 b ± 0.6 | 6.44 a ± 0.6 | 12.97 b ± 2.2 |
| Bulk density (Mg $m^{-3}$) | 1.76 a ± 0.03 | 1.46 b ± 0.02 | 1.66 a ± 0.03 | 1.54 b ± 0.03 | 1.76 a ± 0.04 | 1.47 b ± 0.02 |
| Sand (%) | 95.9 a ± 1.1 | 96.9 a ± 1.1 | 95.5 a ± 1.2 | 95.0 a ± 1.1 | 95.9 a ± 1.2 | 93.4 a ± 2.2 |
| Silt (%) + clay (%) | 4.1 a ± 1.1 | 3.1 a ± 1.3 | 4.5 a ± 1.1 | 5.0 a ± 1.2 | 4.1 a ± 1.3 | 6.6 a ± 2.2 |

Means (± sd) of each parameter into the same system followed by different letters differ statistically ($p \leq 0.05$).

The farm contains, in an area of 5 ha, 1,500 fruit trees, mainly banana (*Musa sapientam)*, citrus (*Citrus* sp.) and mango trees (*Manguifera indica*) planted in a non-organised manner, however the farm has an obvious vertical structure. Other than compost fertilisation and irrigation, no other specific management practices are applied.

2.2.4. Site amended with green manure (**GM**)

This agricultural system corresponds to a cassava plantation in a savanna ultisols located in "El Palmar" near Sabaneta de Guayabal (Figure 1), where a native community fertilises the cassava plantation with the crop residues; consequently although the agricultural system is organic, the input occurs in a very low dressing (Table 1).

*2.3. Inorganic Agricultural Systems* (**IS**) *Assessed*

2.3.1. Traditional cattle ranch (Hato llanero) cropped with Brachiaria (**I 1**)

The traditional cattle ranches from the Orinoco llanos (located in the northern limit of Amazonas state) have been introduced in the surrounding of Puerto Ayacucho, the survey included rancho Amador where Brachiaria grass has been fertilised with NPK and lime. The Brachiaria grass is currently used to complement the low productive local grasses (*Trachypogon* sp. and *Axonopus* sp.) for animal nutrition.

2.3.2. Association of grass and leguminous inorganic fertilised (**I 2**)

The site corresponds to an experimental plot in a savanna ultisol located near the Amerindian community of Sabaneta de Guayabal, 60 km south of Puerto Ayacucho (Figure 2). The agricultural system was used to study the possibility of the establishment of permanent grasses in association with grass legumes for cattle raising and cropping. The 360 m × 90 m plot was evenly divided into two semi-plots, one of them was kept as natural savanna (**NS**), the other half of the plot had been tilled and fertilised with doses of 1,000 kg of phosphate rock $ha^{-1}$ and 300 kg of NPK (12-24-12) $ha^{-1}$ before planting the grass *Urachloa dictyoneura* in association with the legumes: *Stylosanthes capitata* and *Centrosema macrocarpum.*

*2.4. Soil Sampling*

All the different agricultural systems analysed correspond to sites previously established by indigenous and/or farmer communities according with local management practices, consequently we did not participate in the management (fertilisation, cropping, etc) of those agricultural systems, therefore an exact record of fertilisation cannot be provided, except for the experimental plot in Sabaneta de Guayabal named (**I 2,** Table 1), that was established by Universidad Central de Venezuela (UCV), Facultad de Ciencias and Fondo Nacional de Investigaciones Agrícolas (FONAIAP).

Triplicate soil samples in the agricultural systems and in the adjacent control soils were collected during the growing season (rain season) at each experimental site. Each triplicate was a composite sample of ten soil subsamples collected at random from 0 to 10 cm soil layer in the amended site and in the adjacent savanna control. After drying and sieving through 2-mm mesh, soil samples were analysed for soil pH (measured in a ratio 1:5 soil: water), organic matter content according to Walkley and Black method [27] , total nitrogen (Kjeldahl method) according to Anderson and Ingram [28]. N potentially mineralisable was measured after one month incubation according to the method of Stanford and Smith [29]. Available phosphorus was extracted by Olsen and Sommers [30], whereas phosphorus in the extracts was determined by Murphy and Riley [31] method. Exchangeable bases were determined by atomic absorption after extraction with ammonium acetate (1M) at pH 7.0 [27]. Soil moisture (gravimetric method), soil texture (mechanical analysis) and bulk density in triplicate samples were analysed according to Casanova [32].

#### 2.4.1. Microbial biomass and enzymatic activities

Intact sub samples of the above collected soils were used to characterise complementary biochemical and microbial parameters. Intact subsamples for biological analysis were immediately stored at 4 °C until analysis. Triplicate 15 g aliquots of intact soil were used to determine N microbial biomass (N-MB) and C microbial biomass (C-MB). C-MB and N-MB were determined by the fumigation-extraction method using alcohol-free chloroform [33,34]. In both cases, MB was calculated as the difference in total C and N extracted in the fumigated and non-fumigated soil [33]. Microbial P (P-MB) was also determined by the chloroform fumigation-extraction method according with Hedley *et al*. [35]. The P-MB was calculated as the difference between P extracted in fumigated and non fumigated soils. The Microbial quotient ([C-MB/C] × 100) was used as the index of the contribution of the microbial biomass to soil organic carbon (C) and it was expressed in percent. Acid phosphatase activity (APA) was determined colorimetrically as the degradation of PNP-P (p-nitrophenyl phosphate) to PNP (p-nitrophenol) after a 30 min incubation of 1g fresh soil sample at pH 6.5 [36], while urease activity was determined according with the method of Tabatabai and Bremner [37]. For microbial and enzymatic activities, values coming from intact soil samples were corrected for humidity contents.

#### 2.4.2. Pedofauna sampling

Soil organism biodiversity was also evaluated in the various production systems by sampling through pitfall traps 12 cm diameter and 10 cm deep, 1/3 filled with formaldehyde 2% and 0.15% liquid soap [8,9]. Five traps were established on each site randomly in a quadrate 100 m² central to the target system analysed and revised after six days.

### *2.5. Statistics*

Variables were subjected to ANOVA with a mean comparison employing the Tukey test ($P \leq 0.05$). Since the assumptions of a normal distribution and equal variances were not fulfilled, the non-parametric Kruskal-Wallis test was used ($p \leq 0.05$). A STATISTICA programme version 5.0 was used.

## 3. Results

### *3.1. Soil Physical Changes of Organic Agricultural Systems* (**OS**)

The bulk density of the **OS a**t the 0 - 10 cm depth was lower (1.46 to 1.54 Mg $m^{-3}$) than that of the **NS** (1.66 to 1.76 Mg $m^{-3}$). The presence of a tree canopy in the **OSs** has influenced environmental parameters, causing in particular a decrease in air-temperature, and soil-moisture contents have increased concomitantly (Table 2) compared to **NS** due to the lower rate of evapotranspiration and higher organic matter contents (Table 3). In all cases, the soils in both organic amended localities (**CM, CHM** and **Comp**) and savanna controls have a sandy texture (above 93% sand content, Table 2).

### *3.2. Soil Chemical Changes of Organic Agricultural Systems* (**OS**)

Soil chemical parameters (pH, organic matter, nitrogen and phosphorus) in the different localities are presented in Table 3. The total organic carbon content (TOC) increased from 6,525 mg $kg^{-1}$ in the residual cassava amended site (**GM**) to a highest value (33,050 mg $kg^{-1}$) in the cow manure site (**CM**), the farms amended with chicken manure (**CHM**) and compost (**Comp**) presented intermediate values (11,575- 12,530 mg $kg^{-1}$); the values in the treatments significantly differed from the control only in the cases of **CM** and **CHM**.

**Table 3.** Soil chemical parameters in control and organically amended plots (**OS**).

| OS | CM | | CHM | | Comp | | GM | |
|---|---|---|---|---|---|---|---|---|
| | T | C | T | C | T | C | T | C |
| pH | 7.1 a ± 0.02 | 5.6 b ± 0.12 | 5.9 a ± 0.03 | 5.4 b ± 0.05 | 5.5 a ± 0.10 | 5.3 a ± 0.04 | 5.3 a ± 0.00 | 5.4 a ± 0.01 |
| TOC (g $kg^{-1}$) | 33050 a ± 12476 | 4475 b ± 1276 | 12530 a ± 4674 | 6950 b ± 463 | 11575 a ± 3445 | 8178 a ±793 | 6525 a ± 496 | 5328 a ± 1026 |
| N (g $kg^{-1}$) | 2107 a ± 1172 | 422 b ± 116 | 557 a ± 29 | 296 a ± 72 | 1078 a ± 123 | 249 b ± 63 | 471 a ± 157 | 278 a ± 27 |
| C/N | 15.7 | 10.6 | 22.5 | 23.5 | 10.7 | 32.8 | 13.9 | 19.2 |
| Avail. P (g $kg^{-1}$) | 113.0 a ± 8.7 | 0.5 b ± 0,5 | 96.0 a ± 11.2 | 2.2 b ± 2.2 | 20.0 a ± 0.5 | 0.6 b ± 0.1 | 0.9 a ± 0.8 | 0.2 b ± 0.1 |

Means (± sd) of each parameter into the same system followed by different letters differ statistically ($p \leq 0.05$). T = Treatment; C = Control; TOC = Total organic carbon; N = Nitrogen; Avail. P = Available P.

Nitrogen in the surface soil tended to be significantly higher in the **OS** compared to the **NS**, with the highest value for **CM** (2,107 mg N $kg^{-1}$), followed by **Comp** site (1,078 mg N $kg^{-1}$), the chicken manure amended location (**CHM**) presented an intermediate value (557 mg N $kg^{-1}$) whereas the cassava amended location (**GM**) presented the lowest value (471 mg N $kg^{-1}$) (Table 3).

Organic fertiliser introduced substantial and, of course, different amounts of both C and N in the amended sites, consequently a definite trend was not found in the C/N ratios when comparing treatments and associated controls.

Available phosphorus presented the highest increment in **CM**, followed by **CHM**, the **Comp** site presented an intermediate increment (Table 3); whereas, the cassava (**GM**) amended site presented the lowest increment (Table 3). The natural acidity of the soil (pH ranged from 5.4 - 5.6) was neutralised in **OS** amended with cow and chicken manure (pH ranged from 5.9 - 7.1), whereas in the case of the residue of cassava and compost amended sites there were not significant differences in pH with respect to the control savanna soil. Exchangeable bases were much higher in the organic amended sites (**CHM**, **Comp** and **CM**) with respect to the control savanna soils which explain the increment in pH in those agro systems (Table 4).

**Table 4.** Exchangeable bases in the organic amended sites and in the associated control soils.

| Organic agricultural system | CM | | CHM | | Comp | |
|---|---|---|---|---|---|---|
| | Control | Treatment | Control | Treatment | Control | Treatment |
| Magnesium (μg/g) | 26 b ± 1.5 | 811 a ± 13 | 30 b ± 1.2 | 349 a ± 5 | 16 b ± 0.2 | 145 a ± 11 |
| Calcium (μg/g) | 162 b ± 10 | 1555 a ± 17 | 175 b ± 13 | 1954 a ± 25 | 60 b ± 1.4 | 864 a ± 67 |
| Potassium (μg/g) | 60 b ± 6 | 232 a ± 0.0 | 68 b ± 2 | 167 a ± 5 | 42 b ± 1 | 108 a ± 3 |

Means (± sd) followed by different letters differ statistically ($P \leq 0.05$).

### *3.3. Microbial C, N and P in Organic Agricultural Systems (OS)*

The most active forms of C and N corresponding to the microbial biomass fractions, increased significantly in the **OS** soil, as compared to the unamended control soil (Table 5), the results were higher in the cases of the systems fertilised with larger manure doses.

**Table 5.** Soil biological parameters in control and organically amended plots (**OS**).

| OS | CM | | CHM | | Comp | | GM | |
|---|---|---|---|---|---|---|---|---|
| | T | C | T | C | T | C | T | C |
| Mineralisable N (μg g$^{-1}$) | 49.8 a ± 29.7 | 16.1 b ± 2.4 | 13.7 a ± 4.4 | 11.0 a ± 1.2 | 23.4 a ± 0.6 | 16.2 b ± 2.1 | 17.7 a ± 4.0 | 12.1 a ± 1.1 |
| C-MB (μg g$^{-1}$) | 122 a ± 59 | 98 a ± 33 | 154 a ± 23 | 54 b ± 22 | 106 a ± 50 | 54 b ± 25 | 81 a ± 44 | 50 a ± 14 |
| Microbial quotient (%) | 0.37 | 2.19 | 1.23 | 0.78 | 0.92 | 0.66 | 1.24 | 0.94 |
| N-MB (μg g$^{-1}$) | 59 a ±38.6 | 8 b ± 2.8 | 19 a ± 2.5 | 12 a ±2.9 | 22 a ± 2.0 | 12 a ± 1.2 | 11 a ± 4.0 | 13 a ± 5.2 |
| C-MB/ N-MB | 2.07 | 12.25 | 8.11 | 4.50 | 4.81 | 4.50 | 7.36 | 3.85 |
| P-MB (μg g$^{-1}$) | n.d. | 0.2 ± 0.05 | n.d. | 0.2 ± 0.1 | n.d. | 0.2 ± 0.01 | n.d. | 0.5 ± 0.2 |
| UA (μg g$^{-1}$h$^{-1}$) | 70 a ± 12 | 39 b ± 13 | 4 a ± 1 | 9 a ± 3 | 12.1 a ± 10 | 9.2 a ± 7 | 30 a ±23 | 32 a ± 3 |
| PA (μg g$^{-1}$h$^{-1}$) | 37.0 a ± 1.7 | 10.0 b ± 2.4 | 27.9 a ± 4.7 | 15.0 b ± 3.3 | 49.6 a ± 1.5 | 10.7 b ± 7.5 | 7.2 a ± 1.5 | 3.2 a ± 1.5 |

Means (± sd) of each parameter into the same system followed by different letters differ statistically ($p \leq 0.05$). T = Treatment; C = Control; C-MB = C Microbial biomass; N-MB = N Microbial biomass; P-MB = P Microbial biomass; UA = Urease activity; PA = Phosphatase activity; n.d. = non detectable.

Microbial C-biomass increased significantly in **Comp** and **CHM**; however no significant differences were found in **CM** and **GM** sites (Table 5). In the case of microbial N-biomass an increment on treatment respect control was found in all the systems analysed, except for the very low fertilised cassava amended site (**GM**), significance however was found only in the **CM.** Values of microbial Pi were very low ( < 1 μg $g^{-1}$), and even not detectable in many cases.

### *3.4. Enzymatic Activities in Organic Agricultural Systems* (**OS**)

The results of the urease activities (UA) (Table 5) resembled the data of the N microbial biomass in the case of **CM**, since the organic amendment significantly increased UA with respect to the control (Table 5). On the other hand, phosphatase activity increased significantly in all the **OS,** except the low fertilised **GM**. N mineralisation values were higher in **OS** than in the respective controls (Table 5), significance was reached only in **CM** and **Comp** sites.

### *3.5. Soil Chemical Analysis of Inorganic Agricultural Systems* (**IS**) *in Savannas*

Soil chemical parameters (pH, organic matter, nitrogen and phosphorus) in each studied locality are presented in Table 6. The farms amended with inorganic fertiliser presented acidic pHs (4.9 - 5.3) that did not differ from the native savanna (Table 6). Contrary to the data obtained for the farms amended with low input of organic fertiliser (**OS**), there was not an important increment in soil chemical fertility due to the presence of the inorganic amendment. Moreover, organic matter values in the Bracharia and in the Brachiaria-Leguminous association sites declined with respect to that of the control (Table 6).

**Table 6.** Soil chemical parameters in control and inorganically amended plots (**IS**).

| **IS** | **Brachiaria-I 1** | | **Brachiaria-Leguminous-I 2** | |
|---|---|---|---|---|
| | **T** | **C** | **T** | **C** |
| pH | 4.9 a ± 0.02 | 4.9 a ± 0.1 | 5.3 a ± 0.02 | 5.3 a ± 0.01 |
| TOC (g $kg^{-1}$) | 4,500 a ± 242 | 5,050 a ± 739 | 4,350 a ± 172 | 5,328 a ± 1026 |
| N (g $kg^{-1}$) | 294 a ± 66 | 298 a ± 83 | 376 a ± 88 | 278 a ± 27 |
| C/N | 15.3 | 16.9 | 11.6 | 19.2 |
| Avail. P (g $kg^{-1}$) | 1.0 a ± 0.04 | 0.1 b ± 0.2 | 0.34 b ± 0.2 | 0.23 b ± 0.1 |

Means (± sd) of each parameter into the same system followed by different letters differ statistically ($p \leq 0.05$). T = Treatment; C = Control; TOC = Total organic carbon; N = Nitrogen; Avail. P = Available P.

Nitrogen on the superficial soils of the **IS** did not differ significantly with respect to the **NS**. Available phosphorus as expected in those well weathered ultisols is negligible with a low tendency to increase after inorganic fertilisation (Table 6).

### *3.6. Microbial C, N and P and Enzymatic Activities in Inorganic Agricultural Systems (**IS**)*

Microbial biomass carbon and nitrogen increased in the treatments respect the NS (Table 7) although significance was not reached. The same trend was found for the microbial quotient and potentially mineralisable N. Urease activities also increased in the treatments of both studied sites; however significance was only obtained in **I 1**. Phosphatase activities differed between treatment and control soil, but did not present a definite trend.

**Table 7.** Soil biological parameters in control and inorganically amended plots (**IS**).

| IS | Brachiaria-I 1 | | Brachiaria-Leguminous-I 2 | |
|---|---|---|---|---|
| | T | C | T | C |
| Mineralisable N (µg $g^{-1}$) | 13.6 a ± 10.9 | 9.9 a ±0.5 | 18.5 a ± 3.9 | 12.1a ± 1.0 |
| C-MB (µg $g^{-1}$) | 78 a ± 35 | 47 a ± 39 | 74 a ± 38 | 50 a ± 14 |
| Microbial quotient (%) | 1.73 | 0.93 | 1.70 | 0.94 |
| N-MB (µg $g^{-1}$) | 20 a ± 3.4 | 13 a ± 0.02 | 20 a ± 7.8 | 13 a ± 5.3 |
| C-MB/ N-MB | 3.9 | 3.6 | 3.7 | 3.8 |
| P-MB (µg $g^{-1}$) | n.d | n.d | n.d. | 0.5 ± 0.2 |
| UA (µg $g^{-1}h^{-1}$) | 73 a ± 0.6 | 43 b ± 30 | 46 a ± 34 | 32 a ± 3 |
| PA (µg $g^{-1}h^{-1}$) | 9 b ± 4.4 | 18 a ± 2.0 | 10 a ± 1.1 | 3 b ± 1.5 |

Means (± sd) of each parameter into the same system followed by different letters differ statistically ($p \leq 0.05$). T = Treatment; C = Control; C-MB = C Microbial biomass; N-MB = N Microbial biomass; P-MB = P Microbial biomass; UA = Urease activity; PA = Phosphatase activity; n.d. = non detectable.

### *3.7. Community Structure and Abundance of Macro Arthropods*

A year of soil organism collection data obtained with pitfall traps showed the diversity of species among the different Venezuelan Amazonian agroecological systems in savannas. Ants (*Hymenoptera*) were the most numerous and diverse group in all the agro-ecosystems studied (Table 8) corresponding to about 65% of the macro arthropods captured.

**Table 8.** Mean (± sd) dynamic density of macroartropods (daily activity per trap) in the organic agricultural systems (OAS) and natural savanna (NS), Amazonas State, Venezuela.

| Groups | Comp | CHM | CM | NS |
|---|---|---|---|---|
| *Formicidae* | 780.4 ± 357.9 | 400.0 ±152.0 | 2660.0 ± 1078.9 | 305.4 ±160.7 |
| *Coleoptera* | 191 ± 51.8 | 54.3 ± 13.2 | 663.3 ± 214.2 | 42.9 ± 26.5 |
| *Hemiptera* | 8.9 | 16.1 | 336.7 | 5.4 |
| *Aphidoidea* | 19.6 | 7.1 | 6.7 | |
| *Homoptera* | 8.9 | 7.1 | 23.3 | 7.1 |
| *Orthoptera* | 71.4 | | | 32.1 |
| *Mantodea* | | | | |
| *Gryllidae* | | 30.4 | 130.0 | |
| *Gryllotalpidae* | | | | |
| *Blattodea* | 85.7 | 5.4 | 3.3 | 1.8 |
| *Psocoptera* | 1.8 | | | |
| *Thysanoptera* | | | 3.3 | |
| *Plecoptera* | | | 10.0 | 12.5 |
| *Dermaptera* | | | | |
| *Isoptera* | 7.1 | | | 1.8 |
| *Araneida* | 28.6 | 7.1 | 36.7 | 23.2 |
| *Diplopoda* | 19.6 | 21.4 | 13.3 | |
| *Chilopoda* | 1.8 | 1.8 | 3.3 | |
| *Isopoda* | 41.1 | 1.8 | | |
| *Scorpiones* | | | | |
| **Total** | 1266.0 ± 387.9 | 562.5 ± 178.4 | 3830.0 ±1134.7 | 432.1 ± 140.5 |

In the case of the **OS** in savannas no big difference was noted in the structure of the communities of macroarthropods between the natural savanna and the chicken amended farm (**CHM**), however the pedofauna activities were higher in the compost amended farm (**Comp**), and, at least, four-fold higher respect **NS** in the Majada (**CM**) (Table 8); undoubtly that increase in pedofauna activity was due to the abundance of resources, as has been seen in the case of *Oligochaeta* communities in farm **Comp** [38].

*Diplopoda*, *Chilopoda* and *Isopoda* groups appear in the **Comp** and **CHM** sites suggesting a greater biodiversity with respect to the natural savanna and **CM**. After ants, *Coleoptera*, *Gryllidae* and *Araneida* were the most abundant macroarthropods collected in the pitfall traps in both savanna and organic agro system, *Blattodea* also has an important activity in **Comp**.

## 4. Discussion

Long-term additions of organic manure have induced significant changes in the soil physical, chemical and biological properties of the sandy savanna soils. In the case of the presence of a tree canopy in the agro-forestry systems (**AFS** corresponding to **CHM** and **Comp** sites, Table 1) that tree canopy has influenced some environmental parameters, causing a decrease in air-temperature, and concomitantly soil-moisture contents have increased (Table 2) due to the lower rate of evapotranspiration and higher organic matter contents (Table 3). As expected, there was an important increment in soil chemical fertility due to the presence of the amendment which, in turn, was related to the quality and amount of the organic fertiliser.

Organic matter additions have a notable effect on water retention capacity (WRC, Table 2), and that increment was very large in **CM** (50%), moderate in the compost amended **Comp** (34%) and of a lesser extent in the chicken manure fertilised **CHM** (11 %) respect **NS**. Similar results have been presented by Hafez [10] and Thiarks *et al*. [39] reporting that the fibrous components in horse and cattle manures ameliorate the water flux through the profile, whereas in the case of poultry manure the effect is insignificant. Schtønning *et al*. [11] in a study with cow manure also registered an increase in WRC and macroaggregates stability in treated soils; they also recorded a decrease in bulk density after manure addition. More, recently Bulluck *et al*. [13] have also reported after two years of management with organic alternative soil amendments that mean soil organic matter, total C, and CEC were higher, whereas bulk density were lower in organic fertilised plots compared to synthetic fertilisers.

The increments in pH were in concordance with the increase in available base values (Table 4), however, it differed according with the composition of the organic materials. Therefore, in **CM**, where the dose of manure was higher (Table 1), there were important changes in Mg and K, respect **NS**, whereas in **CHM**, the greater change occurred on available Ca. The increase in pH in **CHM** was due to the calcium carbonate compound used in the poultry beds.

Savanna soils (**NS**) present very low levels of total organic carbon (4,475-8,178 mg $kg^{-1}$) which agrees with C values reported on savannas with a similar flora composition (*Trachypogon spp.)* in Northern Orinoco [40]. These low C values are strongly related to the low primary productivity of the area, which has been reported as one of the lowest productivity areas in the world. As a consequence of the manure additions, organic carbon increased significantly in **CM**, where values were eight fold greater than in **NS**, whereas in **CHM** the increment was only one and half fold superior and in **Comp** and **GM** sites the increase was not significant. The greater increase on organic matter in **CM** with respect to the other two sites is supported by a higher dose of manure in Majada (10 Mg ha $^{-1}$) respect **CHM** and **Comp** (2 Mg ha $^{-1}$, Table 1). Besides, the manure added in **CM** has recently been deposited and, therefore has not undergone a strong decomposition process as compared with the aged organic amendment in **CHM** and **Comp**. On the contrary, in the inorganic fertilised plots corresponding to the Bracharia, and in the Brachiaria-Leguminous association sites the organic matter values declined with respect to that of the control, it could be due to a consequence of management as has been reported in other tilled savanna soils [23].

Nutrient content, in general, increased on the sandy savanna soils after organic amendment. In Majada, the N increment is striking (six fold the values of **NS**) and concomitant with the urine addition under cow confinement. In terms of P levels, organic additions significantly augmented the scarce P values existing in the weathered savannas´ soils particularly on available P forms (Table 3). Recently, López-Contreras *et al.* [7] have presented a detailed work on the fractionation of phosphorus in the three organic amended sites here studied (**CM, Comp** and **CHM**) referring to the significant increase on both total and available P forms after manure addition. Nonetheless, that P increment did not constitute a pollution threat as presented by Dormaar and Chang [26] for a mollisol fertilised with feedlot manure at three times the recommended loading regime. In fact, water soluble P measured in wells located at the different organic amended sites were below the detection limit (> 0.005 P µg mL$^{-1}$), meaning that although, in the farms, an important enrichment in total P occurred, that was not enough to generate a pollution problem, a situation that is normal in well weathered tropical soils due to their high P-sorbing capacities [41]. Although, total N content, urease activity and N-mineralisation were higher in organic amended sites with respect to the adjacent control soils, nitrogen values from subterranean waters (data no presented) did not reflect, as in the case of water-soluble P, any potential contamination problem.

The use of a single biochemical property to estimate soil quality is a common approach, particularly when the concept of quality refers exclusively to the productive capacity. Most of the researchers have used a general biochemical parameter such: microbial biomass, dehydrogenase activity, nitrogen mineralisation or a specific parameter as phosphatase or urease activities [12,25].

Microbial biomass in the savanna soils was low which is in correspondence with the low soil organic matter content and coarse texture of the soils. In the soils of the Orinoco savannas, in general, the contents of soil carbon biomass (C-MB) are low [12,23]. Values of C-BM presented for Brazilian Cerrado soils are higher (250-850 mg kg$^{-1}$) [42]. The nitrogen microbial biomass (N-MB) followed a similar pattern than the C-MB, e.g. low values associated with the scarce levels of organic matter.

The addition of organic fertilisers increased the levels of microbial-C, however the increments were not as large as in the case of total C, which in some cases were several times superior (case of site **CM**). Surprisingly, the greater microbial-C increment occurred in the case of **CHM** where a lower total C is presented compared with **CM** and **Comp** sites. That information is partially reflected in the microbial quotients (Microbial biomass C ÷ Organic C), where a slightly higher value was found in the case of **CHM** and **Comp** with respect to the controls (Table 5), however in the **CM** site amended with cattle manure, the microbial quotient (0.37) was very much under the control value (2.19), which without a doubt is associated to the greater organic content in this site. Microbial N-biomass, urease activity and N-mineralisation (Table 5) also significantly increased after organic amendment; particularly under cattle slurry amended site (**CM**). Ureasic activity however is strongly affected by the time of excreta deposition as have been previously reported by López-Hernández *et al*. [8] for Majadas of different ages. That information confirms why parameters of the N-cycle such as Microbial N-biomass, urease activity and N-mineralisation have been widely used in the evaluation of changes in soil quality due to soil management [12,43,44].

Although, available P increased in the treated soils, there was no inhibition of phosphatase activity induced by soluble P forms, as previously reported for natural and cultivated ecosystems. Similar results were presented by Dormaar and Chang [26] for less weathered mollisols in Canada. After applications of feedlot manure in higher rates, they found that phosphatase activity was increased by manure addition; however they also reported that the activities never rose above those from the ungrazed native prairie. Microbial biomass P was not detectable in some of the organic systems studied, as usually reported for very high P-sorbing soils, which, in turn are usually very well weathered (ultisols o related soils) [45]. For mollisols, Dormaar and Chang [26] also have reported that smaller lysed than unlysed Po can be found after manure addition, and that was the reason why they did not introduced the lysing path in their Hedley *et al*. [35] procedure.

In the different agricultural systems analysed, although significant changes were found for several soil quality indicators, the changes were not so evident in many of the cases; particularly in the cases of the inorganic amendments. Concentrations of carbon, nitrogen, phosphorus, potassium, calcium and magnesium were greater in soils with incorporated manure (Tables 3 and 4); similar results were presented by Bulluck *et al*. [13] in organic fertilised farms from Virginia and Maryland in the USA.

In this study it was found a successful adaptation of agroforestry systems (**AFS**) and Majada in sandy savanna ultisols and entisols by amelioration of the soil structure and fertility using animal manure. Agricultural system that use organic amendments in savannas, tend to enhance crop diversity and soil fauna biomass. Moreover small patches of forest recovery have spontaneously appeared in the savanna organic farms within a few years. Pitfall traps have shown dominance of ants in savanna sampled plots (Table 8). In general the forest-savanna ecotone is dominated as expected by ant's activity. Arboreal vegetation in savannas seems to have a similar function than hedgerows in the rural landscape in temperate countries, which is to preserve and disseminate biota over the more disturbed landscape mosaic [46].

Organic fertilisation induces not only changes in the physical and chemical characteristics of the soil; but also induces a very substantial modification of the micro climate of the area as a consequence of the presence of tree canopies [9,38]. Trees in the farm can either be planted as it is the case of citrus and other species of economical importance as Musaceas, mangoes (*Mangifera indica*), or appear naturally, as part of the surrounding forest vegetation. Annual crops are also produced, particularly cassava (*Manihot esculenta*) and cowpea (*Vigna unguiculata*). However, organic manure used in AFS might produce some harmful effects in the environment that could, in turn, affect the sustainability of the system. In the case of the sandy soils of the Amazonian region, the high temperatures contribute to a rapid oxidization and mineralisation of the organic inputs [8]; preliminary results from well waters surrounding organic fertilised sites, have not showed however any soluble nitrogen harmful effects. Nonetheless, there is the need for a more precise determination of the environmental effects of the animal manure in the savannas.

In the San José (**CHM**) and Cachama (**Comp**) farms it was found that compared to the natural savanna, the biomass and diversity of the pedofauna as well as soil fertility had greatly improved

(Tables 3, 4, 5 and 8) allowing the establishment of a sustainable system. As a consequence, the family group has food self-sufficiency in some crops (cassava and some fruits) and eventually could obtain a surplus to sell in the market. In the Granja San José (**CHM**), raising chicken for the market provides the main income for the family. In the long term, that activity is not economically sustainable because it is affected by the high prices reached by chicken food when government subsidies are eliminated. Without the use of chicken manure, the Granja San José could go on producing crops without fertilisers for a while given the large stock of nutrients, especially available P that is stored in the soil (Table 3). However, some uncertainties appear on the agroforestry farms concerning the fate of the stock of plant nutrients and residual P, particularly in the case of events of organic fertilising interruption [7].

As in the case of Granjas San José and Cachama, the Majadas showed drastic increases in soil fertility and pedofauna activities due to the use of cow manure (Tables 3, 4, 5 and 8). In fact, in the Majadas of the village of Provincial, after the addition of organic manure, all the parameters associated with chemical fertility increased. The cost of Majada is large since it relies entirely in the manure of animals which are fed with large amounts of very low quality pasture (*Trachypogon* and associated pastures) thus requiring exploitation of an extensive surface. Ecological stability in Majada is in generally affected by the same constraints found in **AFS**.

Many authors have emphasised that to be useful, values of soil quality indicators should reflect management impacts on soil functions [5,25,44]. Indicators measured in this research were chosen mainly to help interpret the effects of organic and inorganic management impacts on soil functions associated with sustaining biological productivity. Moreover, some of the chosen indicators were associated with maintenance of environmental quality, particularly those related to nitrogen and phosphorus cycling. Besides, the research described the use of faunal groups as indicators for soil quality, particularly by analysing macro arthropods populations, earthworms were well evaluated in previous reports [12,38].

Despite the advantage over inorganic fertilisation, the extensive implementation of the agroforestal system (**AFS**) in the area is, at present time, limited due to different socio-economical and/or related factors that mainly include: firstly, the lack of organic fertiliser sources in Venezuelan Amazonian since animal production is a recent activity in the zone, and secondly the high and fluctuating prices of animal food used to produce that manure.

Nonetheless, the savannas near Puerto Ayacucho are strategically located since they are easily accessible, they cover extended surfaces of the northern and southern parts of the capital; those lands, although nutrient depleted, must be incorporated in the agricultural-production scheme. A low input technique as proposed by López-Hernández and Ojeda [47] might be an alternative.

## 5. Conclusions

The use of organic waste as alternative soil fertility amendments in nutrient sandy depleted savannas soils of Venezuelan Amazonian have resulted in increased organic matter and biological activities in soils respect inorganic fertilised or non-fertilised natural savanna soils, indicators which, in turn, may be related to crop productivity.

The use of organic waste as alternative for recovering of soil of Venezuelan Amazonian increased organic carbon content, soil microbial biomass and pedofauna activities respect to soil inorganically fertilised or non-fertilised natural savanna soils.

An evaluation of the *ex-post-facto* experiments here analysed suggests the convenience of local government policies to consider the possibility to re-establish the subsidy of animal food or incorporate alternative production systems, such as those relying on composting, in order to incorporate more savanna areas to agricultural activity. Policies must be generated within an approach of sustainable agriculture which considers the health of the soil fertility and biodiversity, as well as protecting the natural and human (cultural) resources. The information here presented would be very useful to be utilised for the soil rehabilitation in the South American savannas.

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