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Manure Source and Cropping System Affect Nutrient Uptake by Cactus (*Nopalea cochenillifera* Salm Dyck)

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Abstract: Forage cactus responds positively to organic fertilization. However, little is known about the mineralization dynamics of the various sources of existing organic fertilizers. Thus, the objective was to evaluate the release of nutrients from different manure types and the nutrient accumulation in forage cactus across different cropping systems. Different manure sources (cattle, goat, sheep, and broiler litter) were evaluated for the following cropping systems: (i) *Gliricidia sepium* intercropped with cactus cv. IPA-Sertânia; (ii) *Leucaena leucocephala* intercropped with cactus cv. IPA-Sertânia; and (iii) Cactus cv. IPA-Sertânia in monoculture, in the tropical semiarid region of Brazil. The rate of decomposition and release of N, P, and K from manure was determined by incubating a litterbag, evaluated in different periods (0, 4, 8, 16, 32, 64, 128, and 256 days). Broiler litter released the greatest amount of N and P. Sheep manure released the greatest amounts of K. The greatest accumulations of N, P, and K in cactus biomass occurred when broiler litter was applied. Cactus monoculture accumulated less N over 256 days, indicating that the presence of tree legumes favors the accumulation of N in cactus. Broiler litter promoted the best synchronism between N release and N uptake in different cropping systems.

Keywords: organic fertilization; semiarid; synchronism; Gliricidia sepium; Leucaena leucocephala; Nopalea cochenillifera

1. Introduction

Forage cactus is an important source for animal feed in different arid and semiarid regions of the world. The productivity of this crop is affected by management [1], cultivar [2], planting spacing [3], among other factors. The cultivar IPA-Sertânia (*Nopalea cochenillifera* Salm Dyck) is an important option in the Brazilian semiarid mainly because it is resistant to prickly pear cochineal *Dactylopius opuntiae* [4]. The xerophytic habit and the crassulacean acid metabolism (CAM) that leads to morphophysiological changes under adverse conditions [5] make this forage species an important alternative for areas with erratic rainfall distribution. This cactus variety is productive and is a source of energy for livestock; it is rich in non-fiber carbohydrates, total digestible nutrients, vitamins, minerals, and water. However, it has lesser fiber and protein concentrations than the typical values observed in other forages [6].

Integrating forage legumes in cactus cropping systems provides an opportunity to supply fiber and protein, in addition to increase N availability in the system [7]. Nitrogen input from biological N_2 fixation benefits the nutrient cycling process by adding litter with low C/N ratio [8], with potential improvements in the chemical, physical, and biological soil characteristics. Miranda et al. [1] observed that cactus growing near tree legumes (*Gliricidia sepium* and *Leucaena leucocephala*) produced greater biomass than cactus growing away from the trees.

Normally the cactus is harvested in the field, chopped, and fed to the animals in the trough in isolation or mixed with other ingredients of the diet [9], but it can also be supplied directly in the field, made available on the ground in rows and in some situations used in the form of direct browsing. In addition to the points already discussed, legumes can also be used in the construction of small installations and energy generation due to the potential of their wood [10]. This diversification of forage resources within the production system reduces the need to import feed from other regions, and this is especially important in small properties where resources are scarcer.

Another key management practice to enhance cactus productivity is fertilizer application. Harvesting cactus removes a large amount of nutrients that must be replaced in order to keep the productivity and avoid depletion in soil fertility [11]. Organic fertilizers such as animal manure (e.g., goat, sheep, pig, cattle) have different nutrient releasing rates and are affected by the environment. In addition, it might contribute to improve soil physical, chemical, and biological characteristics. The choice of the best manure application rate varies with environmental conditions and plant population density. Silva et al. [12] observed positive linear response of cactus biomass to cattle manure up to 80 t ha^{-1} when cactus was densely planted (160,000 plants ha^{-1}), resulting in a biennial productivity of 139 t DM ha^{-1}.

Manure from different animal species have contrasting chemical composition and might result in different decomposition rates [13]. Our hypothesis is that the decomposition rate of different manures will vary, with faster rates observed in manures with lesser C/N ratio, consequently leading to a greater nutrient accumulation in cactus amended with these manure types. Understanding the dynamics of mineralization from different sources of organic fertilizer in cactus cropping systems is essential for efficient management practices aiming the synchronism between nutrient release by manure and nutrient uptake by plants. Thus, the objective was to evaluate the release of nutrients from different manure types and the nutrient accumulation in forage cactus across different cropping systems.

2. Materials and Methods

2.1. Site Description

The study was conducted at the Experimental Station of Caruaru, which belongs to the Agronomic Institute of Pernambuco, IPA (8°14′ S and 35°55′ W). The predominant soil in the experimental area is Regosol [14], and its chemical characteristics are on Table 1. The climate of the site is dry and hot semiarid, classified as BSh according to Köppen, with a rainfall volume and average temperature of 727 mm/year and 28 °C, respectively. Figure 1 shows the monthly rainfall data during the experimental period (356 mm).

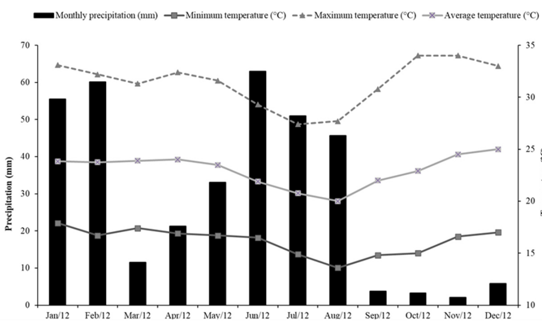

Figure 1. Meteorological variables during the experimental period in areas cultivated with forage cactus in Caruaru, PE. Arrows indicate the beginning and end of the trial period. Source: Agronomic Institute of Pernambuco—IPA (2013).

Table 1. Soil physical and chemical characteristics in the experimental area at different soil layers.

Attributes	Soil Layer (m)		
	0–0.10	0–0.20	0.20–0.40
Sand (g kg^{-1}) [1]	746	748	-
Silt (g kg^{-1}) [1]	146	136	-
Clay (g kg^{-1}) [1]	108	116	-
Textural class		Sandy	
pH (H_2O) [2]	4.8	4.7	4.7
P (mg/dm^3) [2]	23.5	15.5	6.2
Ca (cmolc/dm^3) [2]	1.93	1.76	1.61
Mg (cmolc/dm^3) [2]	0.39	0.45	0.34
Na (cmolc/dm^3) [2]	0.8	0.7	0.9
K (cmolc/dm^3) [2]	0.2	0.1	0.1
Al (cmolc/dm^3) [2]	0.27	0.28	0.31
Al + H (cmolc/dm^3) [2]	2.38	2.32	2.29
TOC (g.kg^{-1})	9.59	8.75	8.91
SOM (g.kg^{-1})	16.5	15.1	15.7

[1] [15]; [2] [16]; TOC: total organic carbon; SOM: soil organic matter.

The experiment was implemented in March 2011. The natural vegetation in the experimental area was the Caatinga, which is native to the region. Legumes were planted in three double rows spaced 9 × 1 × 0.5 m apart. The planting of the IPA-Sertânia cactus was between double rows in monoculture at a spacing of 1 × 0.25 m (Figure 2). In intercropped plots, the density of legumes was 4000 plants/ha and the density of cactus was 32,000 plants/ha, while in isolated cactus cultivation the density was 40,000 plants/ha. In February 2012, the experimental area was fertilized with different manures aiming to supply 200 kg N ha^{-1} based on their respective N concentration (Table 2).

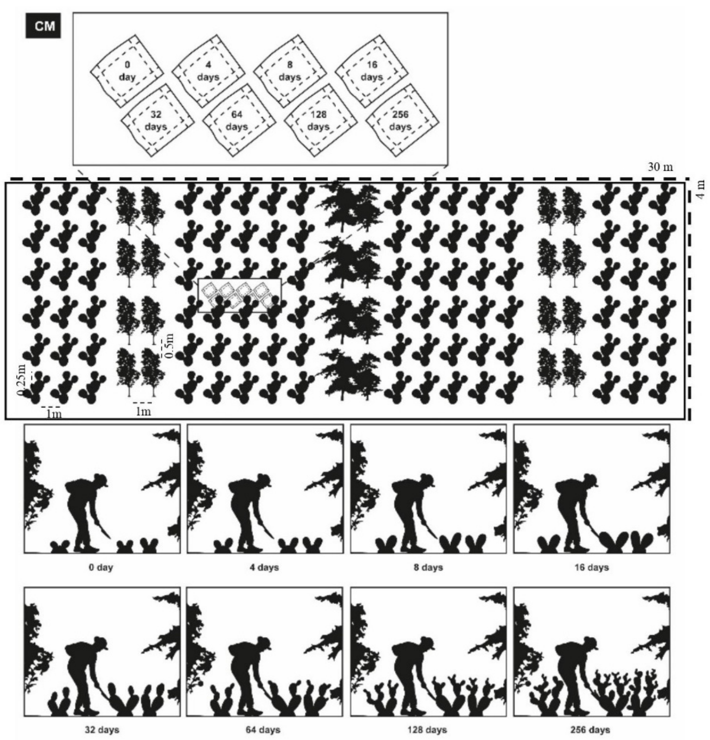

Figure 2. Schematic figure showing parallel retrieval of bags and sampling of cactus to assess manure disappearance and nutrient accumulation in aboveground cactus biomass.

Table 2. Chemical characterization of different manure sources.

Manure	N	P	K	C	C/N	C/P	C/K	OM
		g kg^{-1}						g kg^{-1}
Cattle	11	6	142	232	21	39	2	400
Goat	16	5	107	290	18	58	3	500
Sheep	20	5	157	348	17	70	2	600
Broiler litter	35	31	173	522	15	17	3	900

OM: organic matter.

2.2. Experimental Design

Treatments consisted of different cropping systems (IPA-Sertânia Cactus + Leucaena, IPA-Sertânia Cactus + Gliricidia, and IPA-Sertânia Cactus in monoculture) and different sources of manure (cattle, goat, sheep, and broiler litter). Treatments were allocated in a randomized block in a split-plot design and four replications. The main plot (30 m × 16 m) was the different cropping system, and the sub-plot (30 m × 4 m) was the manure type.

2.3. Sample Preparation and Analysis

The decomposition and the release of nutrients from the different manures were estimated using the decomposition bag method or the litterbag method. Organic fertilizers were dried in an oven (±65 °C) until constant weight, and then weighed and packed in 15 × 30-cm nylon bags with a 75-µm mesh opening. Each bag received 20 g DM of pre-dried manure. This quantity of manure per bag was established according to the proportion of 22.5 mg of manure per cm^2 of bag considering both sides. The incubated manure was not ground; therefore, the particle size represented the manure used in field as close as possible, preserving the original surface from exposure to attacks by microorganisms [17].

The bags were placed in each subplot, covered with a thin layer of soil, and removed according to incubation periods (0, 4, 8, 16, 32, 64, 128, and 256 days) (Figure 2). In each incubation period, a bag was collected from the different sources of manure in each cropping system, totaling 48 bags per period. In the laboratory, the bags were opened. The organic residue contained in them was cleaned with a brush to remove soil residues and dried in an oven (±55 °C) until constant weight. The mass was determined to assess the manure disappearance over time for each evaluation period. Samples were analyzed for DM, N, P, K, and C concentrations [18]. Organic matter was determined through loss on ignition, total nitrogen was obtained by the Kjeldhal method, and P and K were determined using Mehlich-1 extractant followed by reading in a spectrophotometer, and C was determined via oxidation with potassium dichromate [19].

The percentage of nutrients remaining on a given date was calculated based on the contents of each nutrient on that date and the contents on day zero. The percentage of biomass loss based on organic matter and the percentage of remaining nutrients were described using the negative single exponential model [20], described by the equation: $X = B0\ e^{-kt}$, where X = proportion of biomass (or nutrient) remaining in T days, B0 = disappearance constant, and k = relative decomposition rate.

Nutrient accumulation in cactus aboveground biomass was determined by harvesting two competitive plants from each subplot, in each evaluated incubation period (0, 4, 8, 16, 32, 64, 128, and 256 days) preserving the mother cladode (Figure 2). The collected plants were weighed and dried in an oven at 65 °C until constant weight, and then ground at 1 mm. Cladode concentrations of N, P, and K were then determined by the same methods described for the manure.

The amount of nutrient released in the manure was estimated as a function of the remaining amount of manure in the different incubation periods and the concentration of N, P and K in each period evaluated (0, 4, 8, 16, 32, 64, 128 and 256 days). For plant accumulation, the forage production in the cactus plant population was considered, as well as the amount of N, P and K in each period studied.

2.4. Statistical Analysis

The data were analyzed using the Proc mixed procedure of SAS/STAT® 14.1 (Cary, NC, USA) [21]. The blocks were considered random effect. The fixed effects included cropping systems, manure sources, and evaluation dates, which were considered the repeated measure. The means (LSMEANS) were compared by PDIFF adjusted for Tukey ($p < 0.05$). Data was analyzed as split plot.

3. Results

3.1. Manure Decomposition

Manure remaining biomass changed over time ($p < 0.01$) in response to different manure sources and incubation periods (Figure 3). In the initial incubation periods (0 to 16 days), the decomposition rate was similar among the different sources of manure. After 256 days of incubation, the remaining biomass was 98, 90, 88, and 57% for goat, cattle, sheep manure, and broiler litter, respectively. Goat manure had the least decomposition (i.e., greatest amount of remaining biomass in the bag). Concentrations of N, P, and K varied along the evaluation period for the different manure types (Figure 4). However, there was an increase in the concentrations of N (16 days), P (4 days), and K (32 days) in the forage cactus, which then decreased later (Figure 4A).

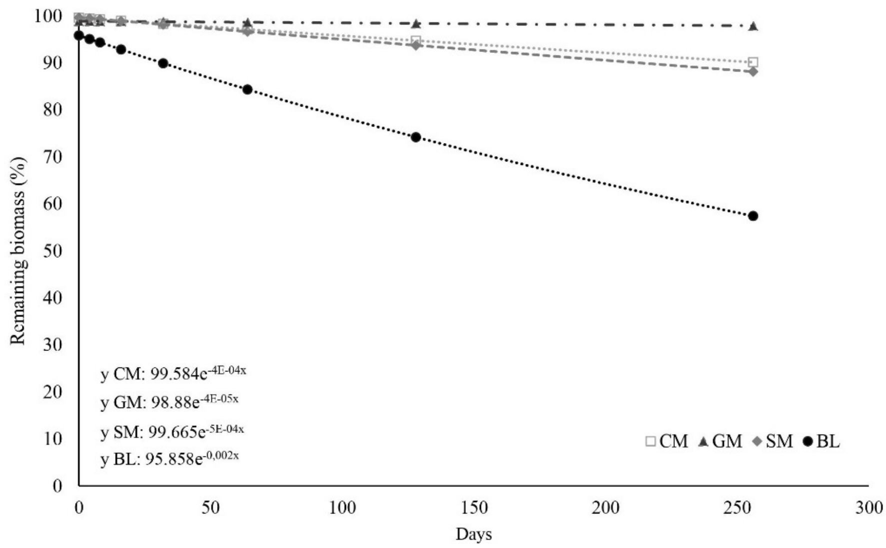

Figure 3. Remaining biomass from different manures in different forage cactus cropping systems. CM: Cattle manure; GM: Goat manure; SM: Sheep manure; BL: Broiler litter.

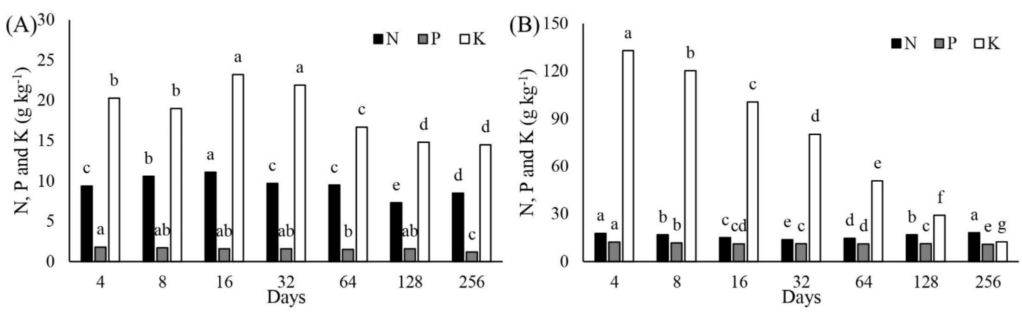

Figure 4. Concentrations of N, P, and K in the IPA-Sertânia cactus aboveground biomass (**A**) and manure (**B**). Different small letters indicate significant difference ($p < 0.05$) within each nutrient by PDIFF adjusted to Tukey.

3.2. Nitrogen Accumulation in Aboveground Cactus Biomass and Release from Manure

The rate of N accumulation by aboveground cactus biomass and manure release was significantly affected by cropping system, manure source, and incubation periods (Figure 5). Cactus accumulated more N in aboveground biomass when intercropped with Gliricidia, regardless of manure source, with means of 0.91, 0.59, 0.55, and 0.50 kg N ha^{-1} day^{-1} for broiler, sheep, cattle, and goat manure, respectively, at 256 days. The greatest N release occurred from broiler litter (56 kg N ha^{-1}) and sheep manure (25 kg N ha^{-1}) at 256 days. Nitrogen disappearance from goat and cattle manures decreased after 64 days of incubation, showing a release rate of approximately 45% of the initial N.

The intercropping of cactus with Leucaena showed a similar behavior as that observed in the intercropping with Gliricidia, i.e., an increase in the N accumulation over the incubation time. Broiler litter and goat manure provided the greatest N accumulations (0.79 and 0.63 kg N ha^{-1} day^{-1}) after 256 days, respectively (Figure 5).

Cactus grown in monocultures had the least N accumulation compared to the intercropped systems. Broiler litter and goat manure provided the greatest N accumulations in this system (0.78 and 0.61 kg N ha^{-1} day^{-1}) at d 256, respectively (Figure 5). The greatest N release occurred in broiler litter and sheep manure at 256 days.

3.3. Phosphorus Accumulation in Cactus Aboveground Biomass and Release from Manure

Phosphorus accumulation rate in cactus aboveground biomass and P release rate were significantly ($p < 0.05$) affected by cropping system, manure source, and incubation period (Figure 6). In the cactus intercropped with Gliricidia, cattle manure provided the greatest accumulation of P (0.09 kg P ha^{-1} day^{-1}) in d 256. Forage cactus had the maximum accumulation of P (41 kg P ha^{-1}) at 256 days. Broiler litter (48 kg P ha^{-1}) and cattle manure (14 kg P ha^{-1}) released more P than other manure types.

Cactus intercropped with Leucaena had a similar P accumulation rate as that of the intercropping with Gliricidia (Figure 6). Cattle manure provided the greatest P accumulation (0.13 kg P ha^{-1} day^{-1}). Goat and sheep manures had an intermediate accumulation (0.12 and 0.12 kg P ha^{-1} day^{-1}) in d 256, respectively. The greatest P release occurred from broiler litter (321 kg P ha^{-1}).

Cactus grown in monoculture accumulated less P compared when grown in intercropped systems (Figure 6). Goat manure provided the greatest P accumulation (0.11 kg P ha^{-1} day^{-1}). The least accumulation occurred in cactus fertilized with sheep manure (0.01 kg P ha^{-1} day^{-1}). The greatest P release occurred from broiler litter (133 kg P ha^{-1}) and sheep manure (11 kg P ha^{-1}).

3.4. Potassium Accumulation Rate in Cactus Aboveground Biomass and K Release from Manure

The K accumulation rate in cactus aboveground biomass and the K release rate from manure were significantly ($p < 0.05$) affected by different cropping system, manure source, and incubation period (Figure 7). When forage cactus was intercropped with Gliricidia, cattle manure (1.18 kg K ha^{-1} day^{-1}) provided the greatest K accumulation. The greatest release occurred in sheep manure (81 kg K ha^{-1}) and cattle manure (45 kg K ha^{-1}) in d 256.

For cactus intercropped with Leucaena (Figure 7), sheep manure promoted the greatest accumulation and release of K (1.42 kg K ha^{-1} day^{-1} and 15 kg K ha^{-1} at d 256, respectively). The least accumulation occurred when cattle manure was applied (0.70 kg K ha^{-1} day^{-1}). For cactus in monoculture, broiler litter provided the greatest K accumulation (1.23 kg ha^{-1} day^{-1}). The K release rate was similar as that observed in intercropped systems. The greatest K release occurred from sheep manure (64 kg K ha^{-1}) at d 256.

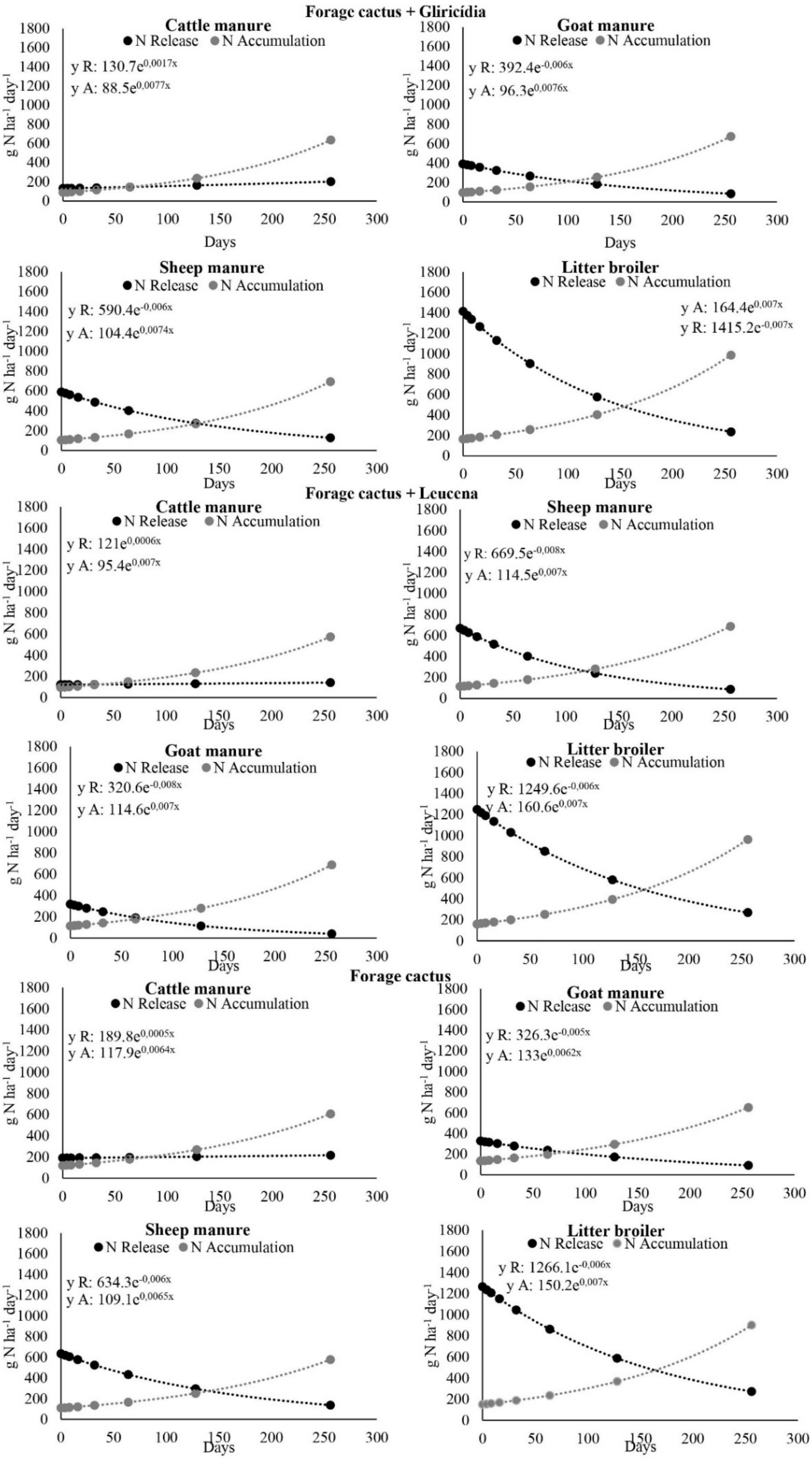

Figure 5. Rate of N accumulation by cactus and release from different manure sources in different forage cactus cropping systems.

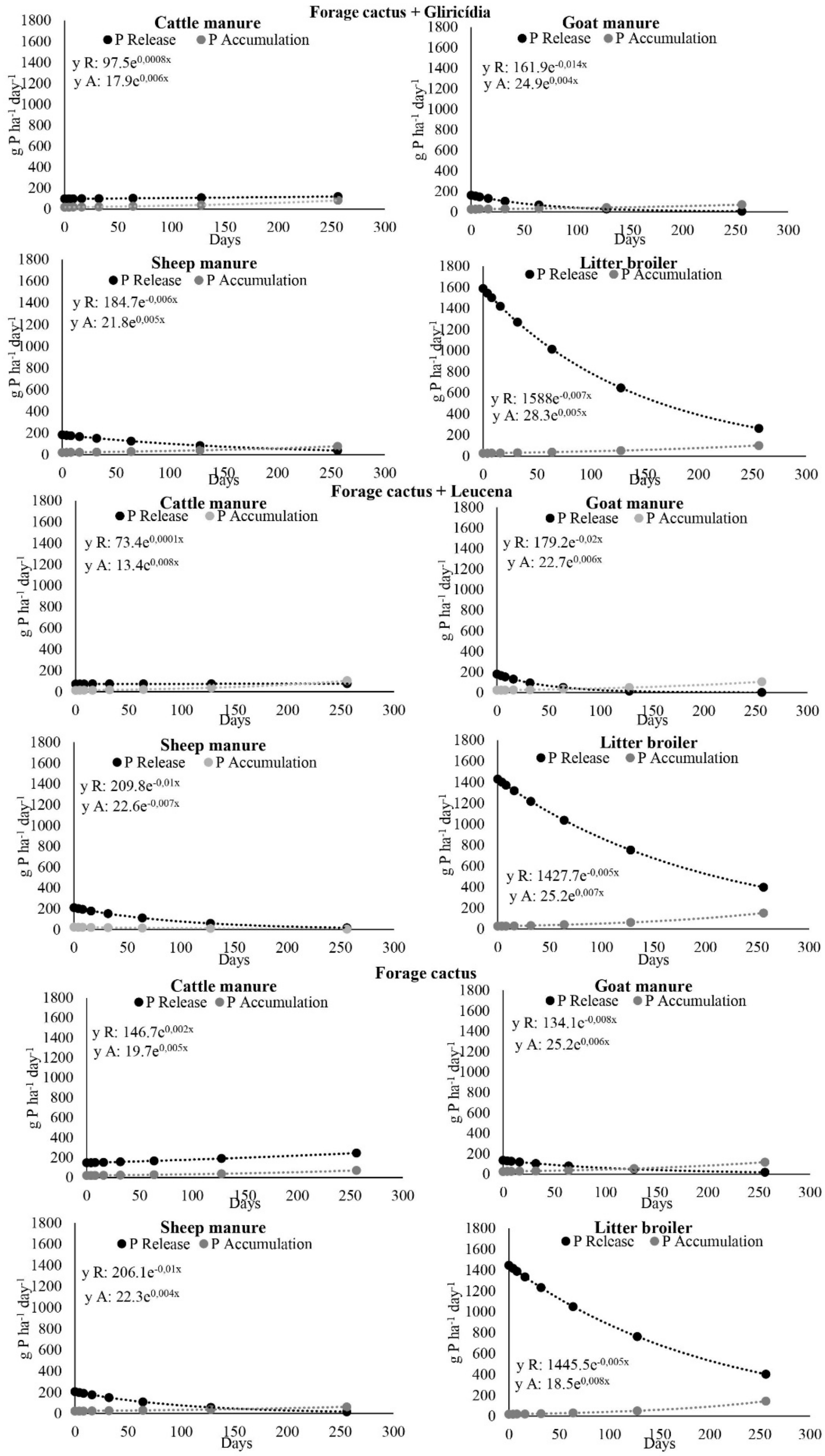

Figure 6. Rate of P accumulation in cactus aboveground biomass and P release from different manure types in a variety of forage cactus cropping systems.

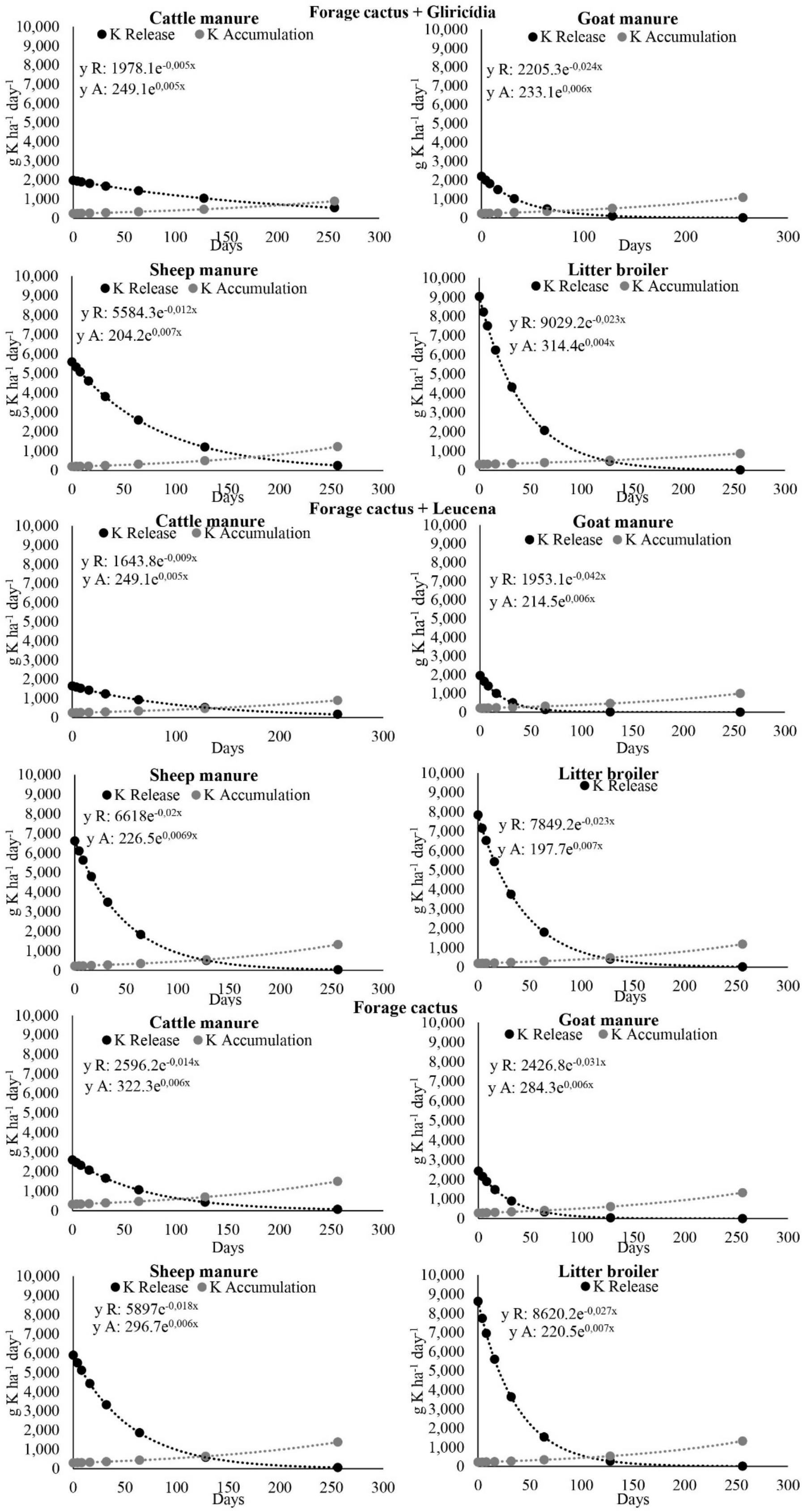

Figure 7. Rate of K accumulation in cactus aboveground biomass and K release from different manure types in a variety of forage cactus cropping systems.

4. Discussion

Nutrient (N and K) accumulation over time in cactus aboveground biomass and the concomitant release of these nutrients from manures (Figure 4) indicate a synchronism. The rapid P disappearance from manures and its steady content in cactus might have occurred because of the soil P dynamics forming stable complexes with amorphous minerals of Fe and Al or lost via leaching [22,23]. Nobile et al. [24] indicated that the application of organic fertilizer may improve the availability of soil P compared to the application of chemical fertilizer.

The slower initial manure decomposition (Figure 3) can be attributed to the atypical rainfall conditions in 2012 with only 360 mm of annual rainfall (Figure 1). Water is essential for the maintenance of microbial activity and decomposition of organic residues because it participates in chemical reactions, diffusion of nutrients, and microbial motility [25]. Another factor that may have contributed to such a slow decomposition is the absence of actions by the macrofauna (>2.0 mm) and the mesofauna (0.2–2.0 mm) inside the litter bags [26]. Such actions break down organic residues and enhances decomposition [27], however, because of the low porosity of the mesh of nylon bags (75 µm) they likely occurred at a lesser extent.

In the different cropping systems, broiler litter showed the greatest release rates for N and P (Figure 3) and the greatest rates of N accumulation in aboveground cactus biomass (Figure 5, Figure 6, Figure 7). These results may be related to the greatest levels of N, P, K, and the least C/N ratio (Table 2) found in broiler litter [28]. Decomposition rate is determined by the quality of organic residues, so that residues with lesser values of C/N, lignin/N, and polyphenols/N ratios decompose more quickly [27,29].

This result corroborates the study of Silva et al. [28], who observed that broiler litter decomposed faster, releasing more N and K than cattle manure. The authors attribute this to frequent microbial attacks to the fractions of broiler litter, as fractions present a greater proportion of easily biodegradable C forms of easier and faster decomposition (e.g., sugars, amino acids, proteins). Broiler litter also has lesser concentration of more complex organic compounds that undergo slower decomposition (e.g., cellulose, lignin, fats). Miranda et al. [1] also observed greater N concentrations in IPA-Sertânia cactus fertilized with broiler litter compared to ruminant (cattle, sheep, goat) manure.

The least N accumulation in cactus growing in monoculture (Figure 5) is probably related to the absence of biological N_2 fixation (BNF) performed by diazotrophic bacteria in symbiosis with legumes [30]. Legumes that were grown in intercropping systems are known for their N contribution to the soil. According to Apolinário et al. [31], Gliricidia may add up to 110 kg N ha^{-1} year^{-1} via BNF. Leucaena can fix up to 80 kg N ha^{-1} in 100 days [32]. It is worth noting that the less accumulation of 0.59 kg N ha^{-1} day^{-1} in cactus monoculture (Figure 5) is probably a result of lesser N inputs due to the lack of tree legumes in that system.

According to Donato et al. [33], in order to produce 21.8 Mg DM ha^{-1} year^{-1} of forage cactus, the requirement is 288, 46, and 924 kg N, P, and K ha^{-1} year^{-1}, respectively. In a forage cactus system intercropped with Leucaena and fertilized with broiler litter, there were probably adequate levels of N and P (423 and 457 kg ha^{-1} year^{-1}, respectively). This manure source released the largest amounts of N and P, an average of 227 and 239 kg ha^{-1} year^{-1}, respectively (Figures 5 and 6). Regarding the K accumulation in aboveground cactus biomass, none of the sources met the requirements of forage cactus. However, there was a greater release of K by sheep manure (76 kg K ha^{-1} year^{-1}) compared with other sources. Goat manure released the least amounts of N, P, and K: 18, 5, and 15 kg ha^{-1} year^{-1}, respectively.

The greatest N release and accumulation of N in aboveground cactus biomass occurred with broiler litter (Figure 5). Some synchronism occurred between nutrient release from manure and accumulation in cactus biomass, however, for all manure types there were times when nutrient accumulation surpassed nutrient release from manure, especially for N and K. For P accumulation, manures generally supplied enough P. It is important to note that despite the greatest P release has occurred in broiler litter, the greatest accumulation occurred in plots fertilized with cattle manure. This can be explained by potential P losses. Thus, Oladipupo et al. [34] recommend mixing broiler litter with other manure (cattle and goat) due to its complementary and its synergistic effect.

Donato et al. [35] demonstrated that the contents of K in the Gigante cactus increase as the doses of cattle manure increase (0, 30, 60, and 90 Mg ha^{-1} $year^{-1}$). Thus, in order to meet cactus K requirements, a dose greater than 200 kg N ha^{-1} is necessary when using similar manure types as the ones used in this study. Lédo et al. [36] observed that organic-mineral fertilization of Gigante cactus promoted greater concentrations of K (39 to 44 g kg^{-1}) when compared with chemical and organic fertilization.

The slow release and accumulation of N, P, and K in cactus aboveground biomass when using goat manure (Figure 7) might be related to a greater C/N ratio in this manure type. Manure chemical composition is closely related to the diets of animals [37]. Goats are more selective animals, and they tend to have an excrement with greater N concentration, however, the physical form of goat feces makes them more difficult for microbial attack [13].

5. Conclusions

Broiler litter decomposes faster than other manure types, releasing the greatest amounts of N and P. However, sheep manure provided the greatest K accumulation in the aboveground cactus biomass. Broiler litter, cattle manure, and sheep manure favors the greatest accumulations of N, P, and K, respectively.

Manure in general provided enough P for cactus growth, however, N and K supply released from manure only met initial cactus demand, with rate of nutrient accumulation surpassing the rate of nutrient release after 100 days in most of the cases. Broiler litter released greater amounts of nutrients earlier in the growth curve, but that might have led to nutrient losses not helping nutrient accumulation in cactus biomass. Combination of organic and inorganic sources of fertilizer or even combination of manure types might be one of the options to match nutrient release curve with crop needs.

The use of legumes in the system might have increased nutrient supply through biological fixation and litter decomposition, helping to supply nutrients to the intercropped cactus.

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