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Evaluation of the structure, functioning and performance of mixed agriculture-animal farming agrosystems

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Abstract

In order to evaluate the structure, functioning and performance of three mixed agriculture-animal husbandry systems of Matanzas province, Cuba, the Ecological Network Analysis was used. Technical data and operational decisions made by farmers at agrosystem level were collected; likewise, the agrosystems LQ (Colón municipality), P (Cárdenas) and CP (Perico) were modeled, in terms of nitrogen flow networks in a one-year period. A flow matrix was constructed for each study case; and structure, functioning and performance indicators were calculated. The density of internal links (Fi/n) was high for the three case studies, with values between 3,37 and 2,88. The flows were more homogeneous in the farms CP and LQ, with organization values of 0,38 and 0,37, respectively. The total internal flows (TT/ha) varied from 476,63 kg N/ha in the farm LQ to 1 941,23 in P, and the N recycling value (FCI) was also higher for these farms (12 and 58 %, respectively). It was proven that farm CP was the one that imported more inputs per area unit (207,6 kg N/ha), and the one with higher productivity value (202,4 kg N/ha). It is concluded that the three agrosystems were similar among them in terms of structure and functioning; they are diverse and complex systems in which differences were observed in the distribution and size of the flows, as well as in the performance indicators.

Keywords: network analysis, flow, nitrogen

Introduction

The challenge of increasing and ensuring food production and reducing environmental problems is increasingly associated with a new paradigm of agricultural production. This paradigm, that is, ecological intensification (Rockström *et al.,* 2017), ecoagriculture (Garbach *et al.,* 2017), agroecology (Altieri and Nicholls, 2017) or modernization of ecological agriculture (Pretty and Bharucha, 2014), aims at designing productive agricultural systems that require the lowest quantity of external inputs, being supported on the interactions and synergies among the biological components (Koohafkan *et al.,* 2012).

The agriculture-animal husbandry integration, acknowledged as the set of agricultural practices that mobilize a series of ecological processes, is one of the pillars of this new paradigm of agricultural production (Stark *et al*., 2016).

Integrated or mixed farming exploitations are often associated with sustainable ecosystems (Alves *et al*., 2017), because integration and diversification, of species as well as practices, allow the complementarity among different activities, and also improve the efficiency in the use of resources. In addition, integrated or mixed systems use the outputs of an activity as inputs for another, which can reduce the adverse effects for the environment and decrease the dependence on external resources through recycling (Rufino *et al*., 2009a).

The energy and nutrient cycles are considered two of the most important attributes that confer stability to the functioning of the ecosystem (Allesina and Ulanowicz, 2004). When admitting structure and functioning properties similar to those that occur in the ecosystems, integration can be analyzed as a nutrient flow network (Stark *et al*., 2016); thus, the most integrated agroecosystem, that is, with more complex and diversified flow networks, will be capable of being more productive, efficient, self-sufficient and resilient.

If the farms are described as networks, in which the different activities are represented as nodes and the nutrients that flow between them as interconnections, management choices can be evaluated. Describing the nutrient flow network within a system can help identify the weaknesses and critical points for the goal interventions (Küstermann *et al*., 2010). The network analysis allows to quantify the degree of integration and diversity of the cultivation system using a set of indicators (Rufino *et al.,* 2009a; Stark, 2016). The objective of this study was to evaluate the structure, functioning and performance of three mixed agriculture-animal husbandry systems of Matanzas province, Cuba.

Materials and Methods

Characteristics of the studied farms. The study was conducted in three farms located in Matanzas province, Cuba: LQ (Colón municipality), P (Cárdenas) and CP (Perico); which were modeled in nitrogen (N) flow networks in a one-year period. The N flows were used to carry out the analysis, because this resource is often the factor that limits production in low-input agriculture and can be managed by the farmers. One year was used as temporary analysis unit, because it is a common period to evaluate the agricultural production.

The climate is characterized by two well-defined seasons: rainy season from May to October (average rainfall of 155,2 mm and temperatures of 26,6 ºC) and dry season since November until April (54,3 mm and 23,6 ºC)[1]. In these farms, the prevailing soil is lixiviated yellowish Ferralitic (LQ), carbonated loose Brown (P) and calcimorphic Humic (CP), according to the classification by Hernández-Jiménez *et al*. (2015).

The three farms are associated to cooperatives of credits and services (CCS) and are managed with family and hired labor; the main characteristics are shown in table 1.

Data compilation. The participant observation model was used in each farm to collect technical data and operational decisions made by farmers

Table 1. Main characteristics of the three farms included in the study.

	Farm LQ	Farm P	Farm CP
General characteristics			
Municipality	Colón	Cárdenas	Perico
Ownership form	CCS	CCS	CCS
Labor	Family and hired	Family and hired	Family and hired
Soil type	Lixiviated yellowish Ferralitic	Carbonated loose Brown	Calcimorphic humic
Use of air pump	Yes	Yes	No
Use of biodigester	Yes	Yes	No
Production factors			
Area (ha)	33	11	45
Agricultural surface (ha)	2,5	5	26
Animal husbandry surface (ha)	30,5	6	18,8
Commercial crops (ha)			
Grains	1,8	-	7,5
Fruits	0,5	3,5	12
Vegetables	0,1	2,13	7,5
Tubers	0,3	0,17	-
Animal husbandry system (number of heads)			
Cattle	70	22	9
Sheep	-	-	5
Horses	3	-	7
Pigs	18	200	-
Rabbits	-	15	18
Poultry	68	50	80

[1]Source: Meteorological Station Indio Hatuey

at agrosystem level (that is, agricultural activities, agriculture-animal husbandry interactions, biomass flows). These data were obtained, during 2015, by a French student of the National Superior Institute of Agronomic Sciences, Food and the Environment of Dijon (AgroSup Dijon), France; supported by researchers and technicians from the Local Agricultural Innovation Program, which is led by the Pastures and Forages Research Station Indio Hatuey in Matanzas, Cuba. In addition, additional data of the DM and N concentration in concentrate feedstuffs, pastures, forages and agricultural byproducts, were obtained, with the support of literature.

System conceptualization. The three agrosystems were conceptualized as systems composed by several compartments, which represent the main agricultural activities, soil and household. The compartments are units that produce and consume biomass. The agrosystems are represented as a network in which the links between compartments represent the biomass flows, in this case referred to kilograms of N per year, within it. The imports of N and the exports are represented as inputs and outputs, respectively, between the farms and the external medium. The losses (dissipation by volatilization, leaching, death of animals) were also taken into consideration as outputs of the compartments. Figure 1 represents the common conceptual model for the three studied agrosystems[2]. A more detailed description of the system conceptualization method was made by Stark *et al.* (2016).

System modeling. Several methods were used to quantify the flows; in the case of the annual flow of materials, it was calculated from the data collected from the farmers in iterative interviews (quantity of feed for the animals and quantity of fertilizers, concentrate feed composition, mineral fertilizer composition, crop and livestock production, organic fertilization, distribution of crop residues, among others). The N content of the material was estimated through the literature data.

The compiled and estimated data were used to construct a matrix for each case study; and based on the flow matrix, the indicators of structure, functioning and performance were calculated (table 2), adapted to the agrosystems by Rufino *et al.* (2009a) y Stark (2016).

The details about the network analysis indicators and the way to calculate them are in correspondence with the statement by Rufino *et al.* (2009a) and Stark (2016).

Results and Discussion

The density of internal links (Fi/n), indicator that shows the diversity of flows, was high for the three case studies (table 3), with values that varied between 3,37 and 2,88. From the point of view of the use of N, the farm LQ was the most diverse and in CP the lowest value for this indicator was obtained. Nevertheless, the values did not vary much among farms, and indicate that they are diverse and complex systems.

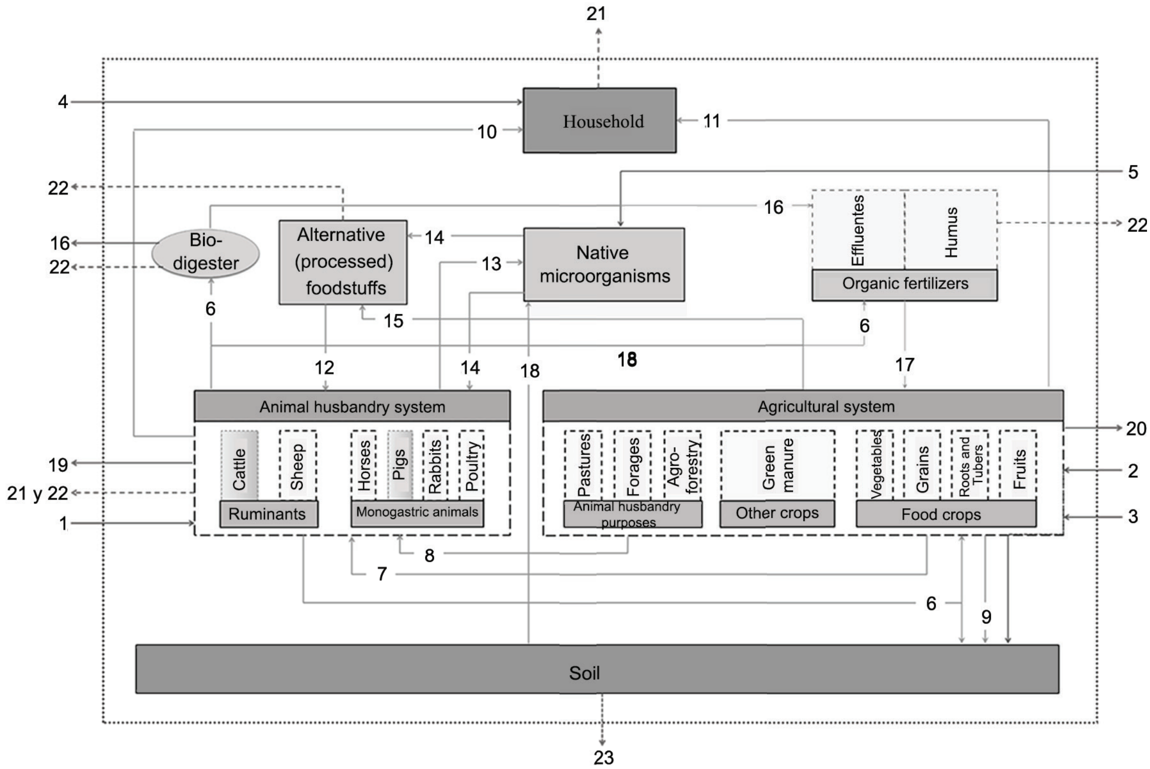
The number and type of compartments to be considered and their interactions have a decisive impact on the configuration of the network and on the value of some of the calculated indicators (Rufino *et al*., 2009b). The conceptual models differ among the studies that use the Ecological Network Analysis (ENA) to evaluate agrosystems, for which comparison is difficult.

For example, Álvarez *et al.* (2014) and Rufino *et al.* (2009a, 2009b) studied in ecosystems of subsistence agriculture and, just like in this research, they considered family as a component of the system, which increases the flows between compartments-. In the studies conducted by Stark (2016) and Stark *et al.* (2016, 2018) several compartments were excluded in the conceptual model (for example: the soil, household, biodigester) their inherent interactions, which explains, to a large extent, the variations in the results. These last authors, when analyzing the flows of N in Cuban farms, but with a different aggregation level of the conceptual model, obtained lower diversity values (1,6; 1,2 and 1,3 for the farms LQ, P and CP, respectively).

In the more diversified mixed agrosystems, where different resources are used to feed livestock and organic matter is utilized to fertilize crops, a more connected and diverse network is constructed. Nevertheless, the number of compartments and interactions between them, present in the agrosystems is much lower than in natural ecosystems; which considerably reduces the flow diversity. Fath *et al.* (2007), for example, refer ecosystems of 60 compartments.

Concerning the organization indicators (1-AMI/Hr), in general, the systems were characterized by a heterogeneous distribution of the flows, that is, there was a disproportion among the internal

[2]In the particular case of farm CP, at the moment of evaluation there was no cattle or pig production and the biodigester was not functioning.



Inputs

1. Inputs to the animal husbandry system (concentrate feeds, drugs). 2. Inputs to the agricultural system (fertilizers, herbicides, biopreparations). 3. Atmospheric nitrogen. 4. Food products of the basic family food basket. 5. Raw materials for the production of native microorganisms (sugarcane molasses, wheat bran).

Intermediate flows

6. Manure. 7. Alternative feedstuffs (direct use). 8. Pastures and forages. 9. Harvest residues. 10. Foodstuffs of animal origin. 11. Foodstuffs of plant origin. 12. Alternative (processed) foodstuffs. 13. Milk. 14. Native microorganisms. 15. Plant biomass (grains, roots and tubers, forages, etc.). 16. Effluents. 17. Organic fertilizers. 18. Litter.

Outputs

19. Sale of animal husbandry products. 20. Sale of agricultural products

Losses

21. Dejections. 22. Emissions. 23. Leaching

Figure 1. Common conceptual model for the N flows of the three studied farms.

flows, inputs and outputs. The N flows were more homogeneous in the farms CP and LQ, with 1-AMI/Hr values of 0,38 and 0,37, respectively; and more heterogeneous in farm P, in which the lowest value of 1-AMI/Hr was obtained (0,26), although it was not much different from the other farms (table 3). These values are similar to the ones obtained by Stark (2016) in Cuba (0,51; 0,39 y 0,46 for the farms LQ, P and CP, respectively).

The organization of flows is a dimension that is rarely considered in the study of farming exploitations, but indicates a new perspective on the system balance, in terms of the distribution of the activity and the complexity of exchanges. The organization of flows not only considers the diversity of connections, but also their distribution among the system components and their relative importance (Stark, 2016).

The three farms did not differ much concerning the organization of their flows (table 3); probably the differences in these indicators would be more evident in systems with a different production and management structure, or when systems in different regions are compared.

In this sense Rufino *et al*. (2009b), when evaluating different types of farms (more diverse, medium and simpler in Ethiopia, Zimbabwe and Kenya, found that the simpler farms tended to show less organized N flow networks, compared with the more complex ones.

A restricted flow network, by which few flows connect few compartments, will restrict the de-

Table 2. Indicators of structure, functioning and agroecological performance for the analysis of agrosystems, based on indicators of the Ecological Network Analysis (ENA).

	Indicator	Mathematical formula
Structure		
Diversity of flows	Number of links in the network	Fi
	Number of compartments	n
	Density of internal links	Fi/n
Organization of the flows	Average mutual information (AMI)	$AMI = k\sum_{i=1}^{n+2}\sum_{j=0}^{n}\frac{T_{ij}}{T..}\log_2\frac{T_{ij}T..}{T_{i.}T_{.j}}$
	Statistical uncertainty (Hr)	$Hr = -\sum_{j=0}^{n}\frac{T_{.j}}{T..}\log_2\frac{T_{.j}}{T..}$
	Done uncertainty	AMI/Hr
Functioning		
Intensity of the flows	Total flows of the system (TST)	$TST = \sum_{i=1}^{n} T_i$
Circulation of the flows	Total internal flows (TT)	$TT = \sum_{i=1}^{j=n} f_{ij}$
	Internal circulation rate (ICR)	$ICR = TT/TST$
Recycling	Finn cycling index (FCI)	$FCI = \frac{TST_c}{TST}$
Performance		
Resilience	System development capacity (C)	$C = -\sum_{i.j} T_{ij}\log\left(\frac{T_{ij}}{T..}\right)$
	Ascendency	$A = \sum_{i.j} T_{ij}\log\left(\frac{T_{ij}T..}{T_{i.}T_{.j}}\right)$
	Reserve capacity	$\phi = -\sum_{i.j} T_{ij}\log\left(\frac{T_{ij}^2}{T_{i.}T_{.j}}\right)$
Productivity	Outputs/total system flow (TST)	$P = \frac{1}{TST}\sum_{i=1}^{n} Y_{0i}$
Self-sufficiency	TST-inputs/TST	$SS = \left(TST - \sum_{i=1}^{n} Z_{0i}\right)/\,TST$
Efficiency	Outputs/inputs	$Eff = \frac{P}{SS}$

k Scalar constant in the AMI equation
$T_{i.}$ Total inputs for the compartment *i*
$T_{.j}$ Total outputs for the compartment *j*
$F_{ij}.T_{ij}$ Flow from compartment j to compartment *i*
$T_{..}$ Total system yield (sum of the links in the network).
$T_i = \sum_{j=1}^{n} f_{ij} + Z_{io} - (X_i)\_$ Intermediate flow of the compartments
$(X_i)\_$ Negative status derived for compartment *i*
$Z_{io}.Z_{jo}$ Inputs to compartment *i* or *j* from outside the network
TST_c Total recycled flow
$Y_{Oi}.Y_{Oj}$ Outputs (usable) of the network for compartment *i* or *j*

velopment of the system. Contrary to this, a strip-shaped pattern corresponding to flows equitably divided among all the compartments, where all of them are connected, will correspond to higher organization.

If they are compared with the intricate architecture of ecosystems, agrosystems are simpler in terms of their flow organizations; nevertheless, they can be more efficient than ecosystems, because a large amount of resources in the network can be

Table 3. Indicators of the system diversity and organization for the nitrogen flows.

Indicator	Farm LQ	Farm P	Farm CP
Diversity			
n	19	17	16
Fi	64	54	46
Fi/n	3,37	3,18	2,88
Organization			
AMI	1,63	2,17	1,73
Hr	2,59	2,94	2,8
AMI/Hr	0,63	0,74	0,62
1-AMI/Hr	0,37	0,26	0,38

Farm: LQ (Colón municipality), P (Cárdenas municipality), CP (Perico municipality)
n: number of compartments
Fi: number of links
Fi/n: density of internal links
AMI: average mutual information
Hr: statistical uncertainty
AMI/Hr: done uncertainty

controlled or exchanged through a limited number of pathways (Stark, 2016).

Because the agricultural practices used in the farms and, consequently, the inherent flows, were not the same, and cropping and animal husbandry systems were not present in the same proportion, the value of internal flows (TT/ha) differed in all the cases (table 4).

Table 4. Functioning indicators of the system for nitrogen flows.

Indicator	Farm LQ	Farm P	Farm CP
Intensity			
TT/ha (kg N)	476,63	1 941,23	1 073,24
ICR (%)	73,86	75,32	71,81
Recycling			
FCI (%)	12	58	0

Total internal flows (TT), internal circulation rate (ICR), Finn cycling index (FCI).

These results coincide with the ones obtained by Stark *et al.* (2016) for this indicator, when evaluating eight case studies in Guadeloupe (346,3 kg N/year in the least intensive systems; 3 802 kg N/year in the most intensive ones) and four in Brazil (634-4 626 kg N/year); comparable with those reported by other authors who used the ENA to analyze integrated systems (Rufino *et al.,* 2009b; Álvarez *et al.,* 2014).

The internal circulation rate (ICR), which summarizes the quantity of N that circulates in the internal flows with regards to the total circulation of the flows (TST), was high and similar for the three cases. The results obtained by Stark (2016) for the Cuban cases indicated that the internal circulation rate of N was lower than that of this study; the ICR value varied from 6,6 % in the simplest system to 49,2 % for the most integrated system, similar results to the ones obtained by this same author in Brazilian farms.

The above-stated facts indicate that a set of management practices, such as the use of animal manure, the utilization of harvest residues for livestock feeding or for fertilization, the production of native microorganisms, the use of biodigester sludge and biogas, among others, have a positive impact on the degree of integration in mixed systems, decreasing the total losses of N in the system.

This coincides with the report by Stark *et al.* 2016), who expressed that the integration in mixed systems can be increased with the intensification of internal flows, through: a better use of available crop residues, or the association of the existing productions with forage production, or a better storage and processing of manure, or the association of crops with legumes, among other practices. Likewise, according to Álvarez *et al.* (2014), the improvement in the management of the use of manure in Madagascar farms led to the reduction of the losses of N and to the increase of integration between crops and animal husbandry and to the global efficiency of N in the farms.

Another indicator that characterizes the integration is Finn index, which is used in the evaluation of natural ecosystems (Allesina and Ulanowicz, 2004) and has been used by several authors to analyze agrosystems (Rufino *et al.,* 2009a, 2009b; Alvarez *et al.,* 2014; Stark, 2016).

The value of N recycling evaluated through the FCI was higher for farm P (58 %), followed by LQ (12 %) and null in CP (table 4). The first two cases were systems that had a strong animal husbandry component and, to a lower extent, agriculture, for which the flows from the animal husbandry activity (animal feeding, dejections, use of the excreta for producing organic fertilizers, their application in the crop area) increased the possibilities of N recycling, due to the intrinsic relations among these compartments. On the contrary, in CP, the main activity was agricultural production and, consequently, recycling within the system was lower; this farm imports manure for producing compost.

In this regard, Gourley *et al.* (2012), when evaluating different dairy systems, concluded that poor exploitation of the excreta results in higher losses of nitrogen and inefficiencies in its recycling. This coincides with the report by Álvarez *et al.* (2014), who obtained low FCI values (between 2,5 and 4,4).

It is necessary to specify that, in agrosystems, the number of flows is less important than in ecosystems, and the possibility of N returning to the same compartment is very small. In the case of the farms L and Q the architecture of the flow network allowed nitrogen to circulate again in the same compartment through several existing routes. in the other case (CP), the flows were in only one direction, which did not allow N recycling and led to a null value of FCI.

Stark (2016) stated the uncertainty concerning the importance of using this indicator to study animal husbandry systems, given the low recycling level of these systems compared with natural ecosystems. In this sense, Finn (1980) obtained 75,8 % of FCI when measuring the nitrogen flow network of the Hubbard Brook ecosystem. Nevertheless, Allesina and Ulanowicz (2004) found recycling values between 0 and 40 % in 23 ecosystems.

The three systems had similarity in terms of structure and functioning; however, they showed contrasting values for the performance indicators, specifically for the dependence on external inputs, productivity and efficiency.

Farm CP was the one that imported more inputs per area unit (table 5), with a similar value to that of farm P, and both were higher than LQ.

Table 5. Agroecological performance indicators for the nitrogen flows.

Indicator	Farm LQ	Farm P	Farm CP
Inputs (kg N/year)	468,0	2 157,7	9 343,7
Inputs (kg N/ha/year)	14,2	196,2	207,6
Dependence (%)	2,2	7,6	13,9

In agreement with the above-stated facts, farm CP showed the highest value of N dependence (13,9 %). The farms P and LQ, with a higher proportion of area aimed at the animal husbandry activity, showed lower levels of N dependence. In the case of CP, the animal excreta had the highest bearing on the inputs imported to the farm; while the concentrate feeds for animal feeding represented a high percentage of the input flows in farm P.

In a study conducted by Rodríguez-Izquierdo *et al.* (2017) in animal husbandry farms of Matanzas province, Cuba, it was found that most of the farms used remarkable quantities of external inputs (for example, fertilizers, pesticides, fuels) and wasted animal production and harvest residues. In that sense, these authors referred that a change in productive systems, focused on the sustainable management of their own resources, with adequate recycling and utilization of the produced nutrients, can contribute to increase efficiency, as well as to generate a favorable environmental impact and better agroecosystem conservation.

On the other hand, Pereda-Mouso *et al.* (2017) reported the reduction of inputs as strategic aspect within the reorganization processes in agriculture in Cuba and as determinant for sustainability; in addition, Ortiz and Alfaro (2014) indicated that sustainable intensification processes should integrate, among other aspects, knowledge and available local resources.

In this sense, Casimiro Rodríguez (2016b) argued that in farming exploitations practices with multipurpose character can be implemented, which propitiate diverse mechanisms that reinforce the immunity of the agroecosystem and in turn respond to several principles; this will allow to reduce the dependence on agrochemicals, fossil fuels and energy subsidies, establishing complex agricultural systems that guarantee their own fertility and productivity.

With regards to productivity per hectare (fig. 2), CP showed a high value (202,4 kg N/ha) and P, a moderate value (120,1 kg N/ha); the latter surpassed LQ, which showed a very low value (13,1 kg N/ha).

Stark *et al.* (2018) obtained, in several case studies in Cuba, productivity levels that varied between 22 and 78 kg N/ha; while, in other farms evaluated in Brazil and Guadeloupe, depending on the region, productivity varied from 13 to 69 kg N/ha. Such results are lower than the ones in this research, with the exception of farm LQ.

The efficiency levels (fig. 2) of CP and LQ were placed in the same range (97,46 and 93,0 %, respectively), and both farms surpassed P (61,2 %). The results obtained by Stark *et al.* (2018) in this indicator were very variable.

It is valid to state that that crop and animal productions do not have the same efficiency in the use of N (Godinot *et al.*, 2015). Agricultural crops are primary producers that use inorganic nutrients to produce biomass through photosynthesis; while almost

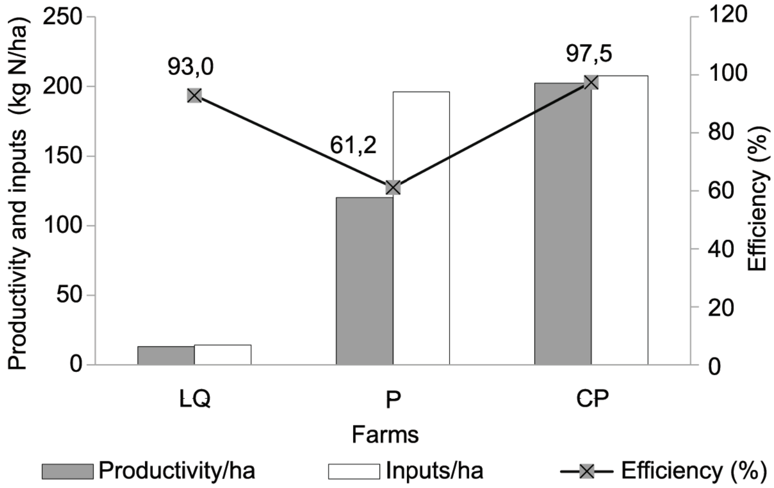


Figure 2. Productivity, inputs (per hectare) and efficiency (%) of nitrogen flows.

all animals are primary consumers that obtain most nutrients and energy from plants. This difference in the trophic level induces a systematic difference in the efficiency of nutrient use (Odum, 1971).

The N transferred from inorganic sources to animal products is based on the efficiency of this nutrient in the plant, but also includes the losses of food production during harvest and the processing, conservation and consumption, as well as the losses to excretion. Thus, N efficiency in animal husbandry systems is biologically lower than in cropping systems (Godinot *et al*., 2015).

It should also be emphasized that the systems with human intervention can be more efficient than natural ecosystems, because a large quantity of resources can be controlled and exchanged in the network through a reduced number of pathways (Pizzol *et al*., 2013). In this sense, studies conducted in Cuba (Rodríguez, 2013) indicate that in mixed and multifunctional agricultural systems, with high levels of integration and animal husbandry-agriculture recycling, higher productivity and efficiency is reached.

The resilience values of the system (fig. 3) were similar for the three farms, although slightly higher for LQ and CP, and indicate that the three agrosystems have wide margin for their progress, because they are halfway through their potential.

Casimiro-Rodríguez (2016a), when evaluating the socioecological resilience of a farm in Cuba during several periods of agroecological transition, found a value of 57,54 % in the first period, when the farm was less diversified and integrated regarding management practices; it was increased to 99,98 % in the final stage, after the incorporation of diverse agroecological practices. First, the improvement resulted from a lower dependence on external inputs and higher production diversity; in the last period the improvement in the utilization of renewable energy sources with the use of diverse technologies had great bearing on the positive results.

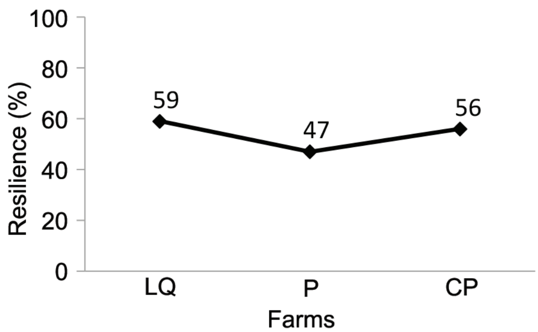


Figure 3. Resilience in the three farms (%).

The resilience of a system depends, to a large extent, on the topography and the pathways through which information, energy and matter circulate. Intuitively, after an interruption, the networks with more diverse connections are more flexible by redirecting their flows and maintaining the critical functions (Kharrazi *et al*., 2016).

Gaba *et al.* (2015) and Stark *et al.* (2016) coincide in stating that the underlying processes to the properties of agrosystem productivity and resilience can be improved with the increase of species diversity and interactions. In this sense, Stark *et al.* (2018) reported that the more connected the flow network is, the higher its adaption capacity will be. Likewise, Goerner *et al*. (2015) stated that as a system has more circulation, its resilience, durability and self-sustainability will be higher.

Nicholls *et al*. (2017), when referring to the principles for the conversion and redesign of agricultural systems, they make emphasis on the fact that the conversion process should be based on the utilization of practices that are not focused on the components in an isolated way, but on exploiting the properties that emerge through the interaction of the diverse farm components. Depending on how certain practices are applied and on their complementarity or lack thereof with others, a particular practice can sometimes act as an «ecological switch», simultaneously activating essential key processes for the health and productivity of a certain cropping system.

Conclusions

Although the value of recycling differed for the three agrosystems, the results indicate that they were similar among themselves in terms of structure and functioning. They are diverse and complex systems, in which a disproportion was appreciated in flow distribution and size. Nevertheless, contrasting values were observed for the indicators of agroecological performance, specifically for the dependence on internal inputs, productivity and efficiency.

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