Scientific Paper

Trophic relations in an agroecosystem of the Sabanas region, Sucre, Colombia

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Abstract

The objective of this study was to define the existing trophic relations in the agroecosystem of a farm in the Sabanas region, Sucre, Colombia. The research started from previous studies in the farm and from field observations between 2014 and 2017. Information of the species was compiled, which allowed to group them according to their feeding habits into trophospecies. The energy flow was shown through a binary matrix of interrelations, and the data were analyzed by designing a trophic network. Six orders, two families, eight genera and one 166 six species were identified. From these groups 11 trophic categories were established: producers, herbivores, nectarivores, granivores, insectivores, carnivores, omnivores, decomposers, hematophages, frugivores and scavengers, distributed in 48 trophospecies. The trophic network showed connection density of 3,25 and a connectance value of 0,13. It is concluded that the trophic network of the agroecosystems allowed to differentiate the fundamental patterns in the trophic organization of the individuals, and showed the importance of some of them in the energy flow between basal and higher trophospecies.

Keywords: biodiversity, energy exchange, trophic levels.

Introduction

Agroecosystems are anthropically intervened systems, that is, their origin and maintenance are associated to man's activity, who has modified nature to obtain goods and services (Sans, 2007). They are formed by biological components which can be divided, according to their function, into producers, consumers and detritivores or decomposers. These biological components show a series of interactions and relations that explain their functions. When one of these components does not function adequately, its structural relations and its functional interrelations with the other components of the biological system are lost, and its environmental integrity is altered.

This occurs when they are overexploited by human intervention and, consequently, degradation and transformation of the natural landscape emerge, which leads to biodiversity loss. According to Zamar *et al.* (2015), animal husbandry systems have undergone transformations in their structure and function, because of their productive simplification, intensification in agricultural practices and reduction of spatial heterogeneity, which generates an intense degradation of the biophysical medium and decrease of sustainability.

In agroecosystems non-lineal tropic relations appear, because the energy flow follows different pathways (Griffon, 2008). Such trophic interactions are a key element of the community dynamics in them and occur not only between adjacent trophic levels, such as crops and herbivores, but also as indirect effects through distant trophic levels (Martínez-Romero and Leyva-Galán, 2014). That is why the studies on trophic networks are fundamental to understand the functioning of ecosystems.

According to Pimm *et al.* (1991), trophic networks are a variant of the system approach; they are represented in terms of trophospecies, which can be basal (without preys), intermediate (with prey and predator) and top (without predator in the community). From the point of view of their structure or topology, they are constituted by nodes, links and trophic levels which describe the diversity, feeding relations, stability and processes that occur within an ecosystem (Pedroza *et al.*, 2016).

The objective of this study was to define the existing trophic relations in the agroecosystem of a farm in the Sabanas region, Sucre, Colombia.

Materials and Methods

Location. The study was conducted in the El Perico farm, located in the Sabanas region (Sucre Department), on the coordinates 9º 12' 41.7" N-75º 24' 09.7" W (fig. 1). The average temperature of the zone is 26,8 ºC, with rainfall that varies between 1 000 and 1 200 mm/year and relative humidity of 77 %. At first, the area was explored, in order to identify the sampling sites where the presence of individuals could be observed, in the plant cover as well as in the soil.

For obtaining and identifying the individuals secondary information of the zone was used; for the frogs, the one reported by Cardozo and Caraballo (2007); for the ants, that stated by Bertel (2015); and for the bats, the one by Sampedro *et al.* (2007). Observations and identifications made between 2014 and 2017, in morning and evening working hours, were included, always taking into consideration the farm limits.

The other information was collected *in situ*: cattle and sheep, sightings and observations with the use of photographs, binoculars and dichotomous keys (birds, reptiles); morphological descriptions, diagnostic traits and use of botanical guides (plants); dichotomous keys (mammals, opossum, sloth, dipterans, hymenopterans, Odonata and coprophages) and direct capture (decomposer invertebrates). After being identified, the individuals were grouped according to their function in the agroecosystem (Pimm *et al.*, 1991). The flora and vertebrate individuals were identified to species; while invertebrates, such as some insects, only to Order.

The species richness, animal as well as plant, was evaluated, according to the report by Moreno (2001), who uses specific richness as the simplest way to measure diversity. The trophic network richness was assimilated as equivalent of the number of defined trophospecies. The trophic structure of the agroecosystems was established organizing the groups depending on their most general trophic strategies, and the classification was based on extensive consultation of the information and the bibliographic data to know the feeding habits (table 1).

Data analysis. To visualize the energy flow of the farm, a trophic network was designed through a static model, based on the structure of a binary matrix, which indicates the presence (1) or absence

Figure 1. Scheme of the El Perico farm.
Source: University of Sucre Planning Department.

Table 1. Species in the agroecosystem El Perico, Sucre, Colombia.

Group	Feeding habit	Taxon
Grasses	0. Primary producer	*Bothriochloa pertusa*
Timber trees legumes	1. Primary producer	*Centrosema pubescens, Vigna unguiculata, Teramnus volubilis, Stizolobium deeringianum, Moringa oleifera, Samanea saman, Leucaena leucocephala, Albizia caribaea, Clitoria ternatea, Pueraria phaseoloides, Arachis pintoi, Cassia tora, Gliricidia sepium, Tabebuia rosea, Senna obtusifolia, Caesalpinia coriaria, Pithecellobium dulce, Bauhinia* sp.
Timber trees	2. Primary producer	*Cordia alliodora, Astronium graveolens, Sterculia apetala, Ochroma pyramidale, Credela odorata, Genipa americana, Guaiacum officinale, Ceiba pentandra, Tectona grandis, Quadrella odoratissima, Bulnesia arborea, Trichilia hirta, Ficus americana, Sapium glandulosum, Ficus benjamina*
Fruit trees	3. Primary producer	*Manguifera indica, Carica papaya* *Spondias mombin* L., *Coccoloba uvifera*, *Psidium araca, Enterolobium cyclocarpum, Cassia grandis, Annona squamosa, Spondia purpurea, Cecropia obtusifolia, Annona muricata, Bactris guineenses, Manilkara zapota, Psidium* sp., *Melicocca bijuga, Cocos nucifera, ertholletia excelsa*
Shrub	4. Primary producer	*Swinglea glutinosa, Gossypium barbadense, Guazuma ulmifolia, Cratylia argêntea, Calliandra pittieri, Capsicum sp., Erythroxylum coca, Tithonia diversifolia, Hibiscus rosa-sinensis, Acacia farnesiana, Euphorbia pseudocactus, Crescentias cujete, Paullinia cupana, Tabernaemontana*
Ornamental plants	5. Primary producer	*Attalea butyracea, Calathea lutea, Bougainvillea glabra, Caryota ochlandra, Veitchia merrillii, Sabal mauritiiformis, Cycas revoluta, Elaeis oleifera, Cecropia peltata*
Aquatic plants	6. Primary producer	*Ludwigia helminthorrhiza, Eichhornia crassipes, Pistia stratiotes, Limnocharis flava, Cyperus* spp, *Carex* sp., *Ceratopteris pteridoides, Phaseolus* sp., *Salvinia* spp., *Azolla pinnata, Lemna minor, Azolla filliculoides, Paspalum repens, Panicum* spp.
Reptiles	7. R1 Herbivores 1	*Chelonoidis carbonaria*
	8. R2 Herbivores 2	*Iguana iguana*
Insects	9. I1 Herbivores	*Tettigonia viridissima, Gryllus* sp.
Bats	10. MU1 Frugivores	*Carollia perspicillata*
Hemipterans	11. H1 Herbivores	Aphidoidea, *Rhodnius prolixus*
Insects	12. I2 Nectarivores 1	Lepidópteros
	13. I3 Nectarivores 2	*Apis mellifera, Xylocopa* sp.
Domestic	14. DO1 Herbivores	*Ovis orientalis aries, Bos taurus, Bos indicus*
Birds	15. A1 Granivores	*Columbina squammata, Columbina talpacoti, Brotogeris cyanoptera,Zenaida auriculata,Sicalis flaveola*
	16. A2 Frugivores	*Aratinga holochlora brevipes, Eupsittula pertinax, Thraupis episcopus, Thraupis palmarum*
Mammals	17. M1 Herbivores	*Bradypus tridactylus*
Insects	18. I4 Insectivores	Macromia dragonfly
Beetles	19. C1 Insectivores	*Coccinella* sp.
Dipterans	20. DIP1 Hematophages	*Haemagogus celeste, Aedes aegypti, Aedes terrens, culex* sp.
Bats	21. MU2 Hematophages	*Desmodus rotundus*
Insects	22. I5 Omnivores	*Polybia emaciata, Vespula germanica*
	23. I6 Carnivores	*Mantis religiosa*
Ants	24. F1 Insectivores	*Camponotus, Labidus*
Arachnids	25. AR1 Insectivores	Araneae

Table 1. Continuation.

Group	Feeding habit	Taxon
Ants	26. F2 Omnivores	*Crematogaster, Ectatomma, Dorymyrmex* *Forelius, Pheidole, Solenopsis*
Frogs	27. AN1 Insectivores	*Leptodactylus fuscus, Leptodactylus insularum, Engystomops pustulosus, Rhinella granulosa, Trachycephalus venulosus, Scinax ruber, Pleurodema brachyops*
	28.AN2 Omnivores	*Pseudis paradoxa, Scinax rostratus* *Dendropsophus microcephalus, Hypsiboas crepitans, Rhinella marina, Ceratophrys calcarata*
Reptiles	29. R3 Insectivores	*Cnemidophorus lemniscatus*
Birds	30. A3 Insectivores	*Colaptes melanolaimus, Campylorhynchus griseus, Bubulcus ibis*
Bats	31. MU2 Insectivores	*Molossus molossus*
Birds	32. A4 Omnivores	*Icterus chrysater, Alcedo atthis, Jacana jacana* *Tyrannus melancholicus, Cyanocorax affinis* *Vanellus chilensis, Quiscalus mexicanus* *Troglodytes aedon, Milvago chimachima* *Pitangus sulphuratus*
Reptiles	33. R4 Carnivores 1	*Helicops angulatus, Liophis lineatus*
	34. R5 Carnivores 2	*Caiman crocodilus*
Birds	35. A5 Carnivores	*Buteo magnirostris*
Reptiles	36. R6 Omnivores	*Kinosternon scorpioides, Mesoclemmys dahli, Trachemys callirostris*
Mammals	37. M2 Omnivores	*Didelphis marsupialis*
Blattodea	38. B1 Decomposers	Blattodea
Termites	39. IS1 Decomposers	Blattodea
Millipedes	40. D1 Decomposers	Polydesmida
Earthworms	41. AN1 Decomposers	Haplotaxida
Ants	42. F3 Decomposers	Formicidae
Coleopterans	43.C2 Decomposers	*Ataenius* sp., *Canthon cyanellus,Onthophagus* sp. *Canthon juvencus, Canthon mutabilis* *Canthidium aurifex, Coprophanaeus gamezi* *Dichotomius agenor, Onthophagus marginicollis*
Gastropods	44. G1 Decomposers	Pulmonata
Fungi	45. HO1 Decomposers	Basidiomycetes
Dipterans	46. DIP2 Decomposers	Calliphoridae
Birds	47. A6 Decomposers	*Coragyps atratus*

(0) of connections. The trophospecies within the agroecosystem and the trophic interactions that can occur among them were recorded. For this network model the free-access program Gephi 091, a software designed for elaborating graphs, managing information, structures, shapes and patterns, utilized by Pedroza *et al.* (2016), was used. For the interpretation of this model, the following attributes were measured: connectance (C=L/S2) and density of unions (L/S), according to Pimm *et al.* (1991) and Dunne and Williams (2009), respectively.

Results and Discussion

The individuals were identified in six orders (Lepidoptera, Polydesmida, Araneae, Haplotaxida, Pulmonata and Blattodea), two families (Calliphoridae, Aphididae), eight genera (*Camponotus*, *Labidus*, *Crematogaster*, *Ectatomma*, *Dorymyrmex*, *Forelius*, *Pheidole, Solenopsis)* and one hundred and sixty six species (table 1).

Based on the feeding habit, 11 trophic categories were established: producers (autotroph organisms), herbivores (organisms that feed on plants), nectarivores (organisms that feed on plant nectar), granivores (organisms that feed on seeds), insectivores (organisms that feed on insects), carnivores (organisms that feed on herbivores), omnivores (organisms that feed on plants and animals), decomposers (heterotroph organisms that feed on detritus), hematophages (organisms that feed on blood), frugivores (organisms that feed on fruits) and scavengers (organisms that feed on decomposing material), distributed in 48 trophospecies (table 2). In terms of number of species, the most diverse groups were the omnivorous and insectivorous trophospecies and the least varied group was that of nectarivorous species.

The above-mentioned feeding habits were grouped into: producers (grasses, timber trees, legume timber trees, fruit trees, shrubs, ornamental plants and aquatic plants), primary consumers (herbivores, granivores, frugivores and pollinators), secondary consumers (insectivores, hematophages, omnivores and carnivores), terminal consumers (carnivores and scavengers) and decomposers (fungi, ants, millipedes, dipterans, coleopterans, Blattodea, termites, earthworms and gastropods). When grouping several species into a trophospecies, their trophic function, that is that they share prey and/or predator in the system, was assumed as criterion. In many aspects, it is fundamental to consider the function and know what the constituent species do, instead of evaluating whether they are present or not in the system (Pedroza *et al.*, 2016).

The trophic network that integrates the agroecosystem community showed 156 connections, which represented the predator-prey relation of the biological components (fig. 2). This value is considered high, if it is compared with the report by Roubinet (2016), who observed only 77 connections. The difference could be consequence of the agroecosystem type, because this last one was developed in a monoculture, which according to Altieri (1995) shows less trophic interactions.

The maximum size of the network was seven trophic levels and the minimum, two, for which the network had a mean size of 4,5; this is unusual in terrestrial and aquatic trophic networks, which normally have three or four levels (Pimm *et al.*, 1991). This condition is consequence of the high number of trophospecies and the presence of a large quantity of consumers. If the network size is considered, it can be inferred that it is a vulnerable network, due to the high energy loss represented by many trophic levels. Nevertheless, the in terms of robustness, it is considered a highly robust network, because if 50 % of the community of producers is withdrawn, the network would remain sustainable (Dunne *et al.*, 2002). The trophic network was strengthened by having seven basal trophospecies which included 90 species, in charge of assimilating energy and passing it to most of the consumers. In addition, the trophic network had the presence of 11 primary consumer trophospecies, which included 23 species, generating high ecological redundancy in terms of functional relations; this guaranteed the energy flow towards higher levels and nutrient circulation (De Ruiter *et al.*, 2005).

The predator trophospecies and most important preys, according to the number of interactions,

Table 2. Trophic organization of the categories in the trophic network and number of trophospecies per each category.

Order of the categories	Trophospecies
1 Primary producers	Plants Trophospecies 0-6
2 Primary consumers	Herbivores, frugivores, nectarivores, granivores Trophospecies 7-17
3 Secondary consumers Lower levels	Insectivores, hematophages, carnivores, omnivores Trophospecies 18-30
4 Tertiary consumers Higher levels	Carnivores, omnivores Trophospecies 31-37
5 Decomposers	Decomposers, scavengers Trophospecies 38-47

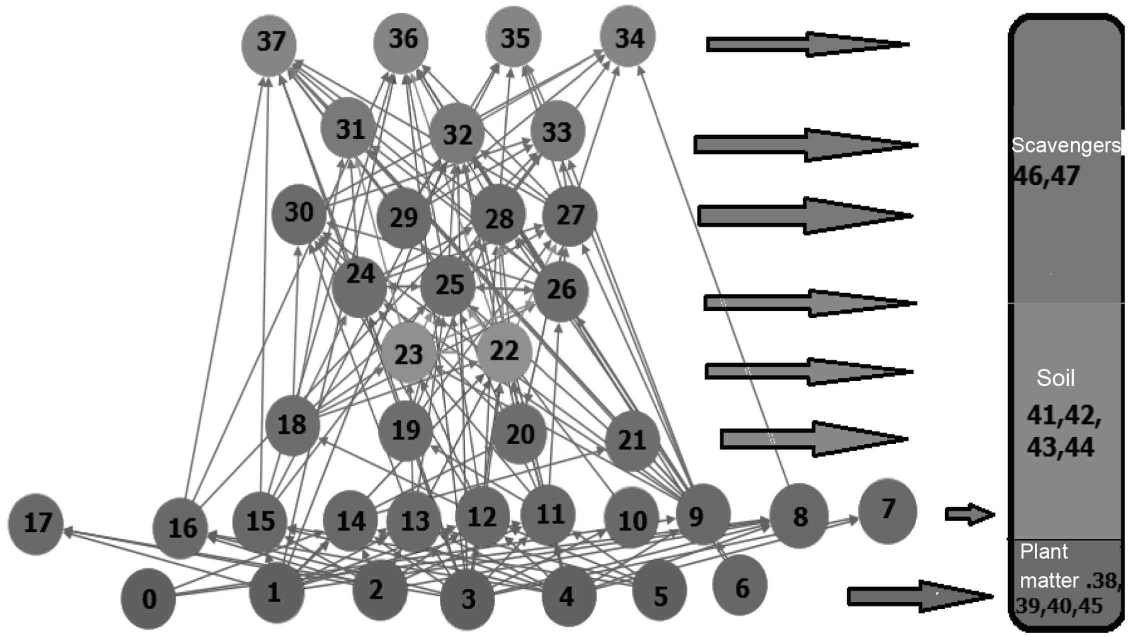

Figure 2. Trophic network of the agroecosystem El Perico.

0) Grasses, 1) legume timber trees, 2) timber trees, 3) fruit trees, 4) shrubs, 5) ornamental plants, 6) aquatic plants, 7) herbivorous reptiles 1, 8) herbivorous reptiles, 9) herbivorous insects, 10) frugivorous bats, 11) herbivorous hemipterans, 12) nectarivorous insects 1, 13) nectarivorous insects 2, 14) herbivorous domestic animals, 15) granivorous birds, 16) frugivorous birds, 17) herbivorous mammals, 18) insectivorous insects, 19) insectivorous beetles, 20) hematophagous dipterans, 21) hematophagous bats, 22) omnivorous insects, 23) carnivorous insects, 24) insectivorous ants, 25) insectivorous arachnids, 26) omnivorous ants, 27) insectivorous frogs, 28) omnivorous frogs, 29) insectivorous reptiles, 30) insectivorous birds, 31) insectivorous bats, 32) omnivorous birds, 33) carnivorous reptiles 1, 34) carnivorous reptiles 2, 35) carnivorous birds, 36) omnivorous reptiles, 37) omnivorous mammals, 38) decomposer Blattodea, 39) decomposer termites, 40) decomposer millipedes, 41) decomposer earthworms, 42) decomposer ants, 43) decomposer coleopterans, 44) decomposer gastropods, 45) decomposer fungi, 46) decomposer dipterans, 47) decomposer birds.

are shown in figures 3 and 4. Their extinction or exclusion could break the relations among the sets of species, and this could seriously damage the integrity of the ecosystems (Perfecto *et al.*, 2014).

Roubinet *et al.* (2018) consider that the trophospecies 9 (herbivorous insects) is industrial, because it shows 13 predators that transfer energy to higher consumers; and the absence of these insects would affect, in turn, the system stability (Macfadyen *et al.*, 2009).

The other trophospecies, mostly, had from three to seven predators as average, with the exception of the trophospecies 8 (herbivorous reptiles 2), 10 (frugivorous bats), 21 (hematophagous bats) and 31 (insectivorous bats) which had only one output in the system. These results were analyzed through the trophic network of the system and showed the importance of each trophospecies. Likewise, the presence of the mammal *Didelphis marsupialis* (fig. 3, trophospecies 37) stood out as regulator species of the community, as it presented 11 preys.

Within the intermediate and top trophospecies, there was a variety of feeding habits; from them the relations of insectivorous groups which comprised eight trophospecies and included 17 taxa and the omnivores which comprised six trophospecies and 28 taxa, prevailed. According to the report by Roubinet *et al.* (2018); this guarantees an energy flow towards the top trophospecies.

Among the network decomposers arthropods were found, which play an important role in the degradation processes of the plant-origin remains. Mutualistic actions with microorganisms were created, by having permanent symbiotic bacteria or protozoa. The most widely known groups are termites (Isoptera) and cockroaches (Blattodea). In this sense, the study of the necrophagous entomofauna and, especially, the coprophagous one, has high ecological and economic interest, because the action of fragmentation and burial of organic remains favors the development of microorganisms and mycelial hyphae which

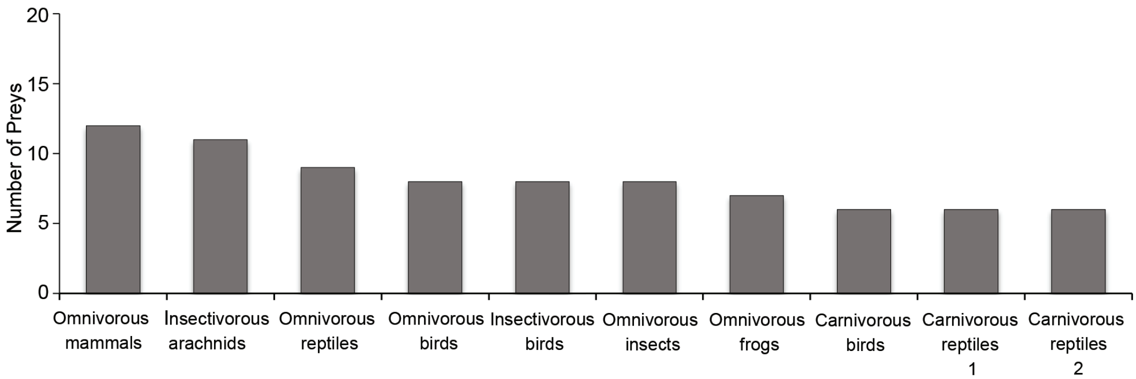

Figure 3. Number of preys for the main predator species in the community. The highest value corresponds to the most generalist trophospecies of the community.

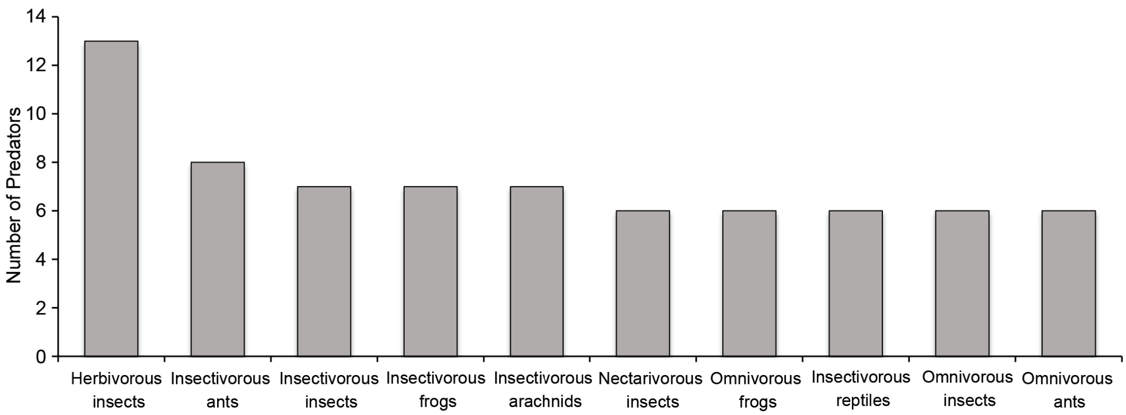

Figure 4. Number of predators for the main prey species in the community. The highest value corresponds to the trophospecies that transports the highest amount of material to the higher trophic levels in the community.

participate in disintegration (Galante and García, 1997). In the pasture areas, as in the case of plot A, this action also has an economic interest (Tovar *et al.*, 2016), because it prevents the accumulation of excrements on the soil, which decreases the availability of pastures and their intake by animals.

In most of the trophic levels the presence of insects was observed. According to their variable trophic characteristics, it is acknowledged that their presence in the system is essential. For example, ants perform important functions, such as soil movement, seed movement and predation; in addition, they have proven to be one of the most sensitive insect groups to environmental changes (Zamar *et al.*, 2015).

For the case of density of unions a value of 3,25 was found, similar to the one reported by Roubinet (2016) in a cereal monoculture (3,6), but different from that of a coffee agroecosystem (Perfecto *et al.*, 2014). From this it is inferred that this attribute is very variable and depends directly on the trophospecies involved in the study and on the functions and relations they are performing in the system. When comparing mixed agroecosystems with the monoculture, there was a significant difference regarding the diversity and function of the species, which could be a little adequate characteristic to confront networks of different sizes and resolutions (Macfadyen *et al.*, 2009). Also when contrasting individually the density values, a medium trophic link is inferred among the formed nodes, because there probably is a high functional diversity within the different established trophospecies (Pimm *et al.*, 1991).

The network connectance was 0,13, value which is considered medium connectivity in the system (Dunne and Williams, 2009). These authors state that the mean connectance values oscillate between

0,1 and 0,15. The values of these study differed from the connectances reported by Roubinet (2016) and by Macfadyen *et al.* (2009), who obtained 0,36 and 0,29, respectively.

These authors structured quantitative trophic networks, which they also considered stable for giving importance to particular interactions of different individuals, depending on the strength of such interactions. The difference in the results is due to the quantity of trophospecies present in the different agroecosystems, because, in their cases, they were monoculture and organic systems, respectively; which have a lower number of trophospecies, for which less interactions occur. From the connectance value it is inferred that in the system there will be a higher degree of recovery in the presence of environmental disturbances (Francis *et al*., 2003).

Conclusions

The trophic network of the agroecosystems allowed to differentiate the fundamental patterns in the trophic organization of the individuals and proved the importance of some of them in the energy flow between basal and higher trophospecies.

Acknowledgements

The authors thank the School of Agricultural Sciences of the University of Sucre and its workers, and the nursery of Aquatic Ecology and Production.

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Received: December 10, 2018
Accepted: July 17, 2019