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Research Article

Evaluation of agrobiodiversity and its trophic interactions as an indicator of sustainability in productive systems

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Abstract

Agriculture has intervened, modified, and simplified ecosystems to obtain some goods and services. Conventional o industrial agriculture emphasizes the use of external inputs and the homogeneity of the landscape; agroecology promotes biodiversity to maximize biological interactions and their ecosystem services. The objective was to evaluate agrobiodiversity and its trophic interactions as an indicator of sustainability by comparing: industrial productive systems, and agro-ecological and semi-natural sites in the southern Pampas region. Samples were taken of mammals, birds, arthropods, and vegetation; with different indices, the food chains and the state of the system were evaluated. The results show that agricultural intensification simplifies landscape structure with a loss of biodiversity and the absence of functional groups (herbivores and nectarivorous). In agroecological wheat, the highest density of links was found and in agroecological pastures the highest grouping coefficient, this reveals greater cohesion and integration among the components of the system and more mechanisms of self-regulation. The agroecological diversity Index showed no differences between the management, this could be related to the presence of a biological corridor in the conventional field that would be increasing biodiversity. The key to achieving sustainable agroecosystems is to procure biodiverse landscapes with patches and corridors of shrub and herbaceous species.

Introduction

The role of biodiversity in agroecosystems has been revalued in recent years due to the ecological services it provides such as nutrient cycling, biotic regulation, pest control, pollination, etc. These ecosystem services derive from the ecological processes of ecosystems and are closely related to biodiversity [1,2]. Ecological interactions are fundamental in ecological pest management, and these interactions form networks. The properties of these networks, where interactions of all possible nature (positive, neutral, negative) coexist, are keys for management [3]. Regardless of the agricultural productive approach agriculture always implies a certain simplification of the ecosystem by reducing its original biodiversity. However, with the current agricultural productive approach, intentional integration of beneficial biodiversity in industrialized agricultural systems can be seen as an impediment to production efficiency in competing for land and resources [4]. Conventional agriculture emphasizes the use of external inputs instead of ecosystem services, as well as genetic and specific uniformity at the level of the lot and even of establishment; which translates into the homogeneity of the landscape [5]. On the other hand, agriculture under an agroecological approach emphasizes the maintenance of adequate biodiversity to maximize biological interactions, synergies, the biomass cycle, and nutrients, to ensure the sustainability of the quality of vital natural resources such as soil and water [6]. In the agroecological literature, it is proposed that increasing

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agricultural biodiversity involves an increase in the number of trophic interactions of the ecological community, which in turn promotes the stability of the whole system [7,8]. Although each species contributes to the functioning of ecosystems, the nature and magnitude of their contributions vary considerably depending on the ecosystem or the process to which reference is made. Therefore, the total set of functional characters, as well as their abundance, in a community is one of the main determinants of ecosystem functioning [9,10].

The Pampas Ecoregion is the most important ecosystem of grasslands in Argentina totaling about 540,000km² and the most transformed by agricultural production. In this region, there was a homogenization of the landscape and a decrease in the biodiversity of wild species typical of the Pampean grassland [11]. Argentine Pampas´ process of agriculturalization over marginal areas and livestock fields continues to transform the region and is especially important in those subregions that until a few years ago appeared as less affected by this process, such as the Depressed Pampa and the Southern Pampa. Currently, these environments are in many cases in a compromised situation in terms of their conservation status and ability to provide ecosystem services. For this reason, the studies proposed in this project were addressed in the Southern Pampa subregion. In this context, we aimed to determine and evaluate agrobiodiversity and its trophic interactions as an indicator of sustainability under different agricultural productive approaches, as well as in semi-natural sites in the southern Pampas. Therefore, it is hypothesized that the agroecological agricultural approach supports greater agrobiodiversity than industrial agricultural systems.

Materials and methods

Study area

The research was conducted at Tres Arroyos Country (38°47′S, 60°06′W), a representative wheat production region in the southern Pampas Ecoregion, Argentina. Three study sites were selected. Two of them were fields, one under agroecological productive approach for six years ("Argelanda" S 38º 19.453´, W 60º 15.284´; 320 ha; Figure 1), and the other under industrial productive approach ("INTA-MDA", S 38º 48.456´, W 60º 06.014´; 311 ha and 70 ha of the forest; Figure 1). Both had a wheat plot and a pasture plot within-field (Agroecological wheat= AEW of 5 ha plot, Industrial wheat= IndW 10 ha plot, Agroecological pasture= AEP of 5 ha plot, Industrial pasture= IndP of 5 ha plot). The third study site was a semi-natural area called "La Isla" (SNat) without management, with the presence of grassy, shrubby, and woody vegetation, both native and exotic (S 38º 50.793´, W 60º 05.241´; 5 ha plot; Figure 1).

Fields were managed commercially and were selected because they are considered typical for the area in terms of their productive approach. Different samples were carried out during the spring of 2017 and 2018. The sampling area was the same at each site, it was 2.5 ha and this was chosen at random within each plot.

Mammals sampling

A sampling of micro-mammals in 2 transects with 25 trapping stations in each one, 20 m apart. Each trapping session lasted 3 consecutive nights at each site. The capture-mark-recapture method was used with Sherman and Tomahawk traps. Each animal was taken by standard morphometric measurements, weight, age, and sex. These measurements were taken for later population work. In this research, we were only interested in determining the species.

The signs of fauna were recorded in 2 transects of 200×10m per site [12]. The animals were determined seen or heard, and the signs of fauna such as feces, footprints, or caves [12-17]. Then, the recorded species were divided into different trophic guilds, such as herbivorous, granivores, insectivorous, omnivore, carnivorous, and nectarivorous using bibliography [18] (**Appendix 1**).

Bird sampling

We made counts for finite radius points, at each point, the radius was 50 m and we observed for 10 minutes making the determinations and counting the birds seen in that circle. There were three counting points per site. We used 10x50 binoculars (Bushnell) and a ground telescope (Bushnell). Each point was georeferenced. For the taxonomy and systematics of birds, we consulted Narosky and Yzurieta [19] and Fangauf and Winkler [20]. Then, the recorded species were divided into different trophic guilds, such as herbivorous, granivores, insectivorous, omnivore, carnivorous, and nectarivorous using bibliography [19,20] (**Appendix 1**).

Arthropod sampling

Pitfall traps were used for sampling ground-dwelling arthropods. At the sites Agroecological and Industrial, a total of 8 pitfall traps (plastic jar, diameter = 11cm, height= 10cm) with a 1000ml capacity, filled with 300 ml of a 5% formalin solution [21] and detergent (~1mL). At each study site, 4 equidistant traps were placed 10m from each other. Traps remained in the field for seven consecutive days [22]. The samples collected were transported to the laboratory, filtered and cleaned of debris and inorganic material, and examined by stereomicroscope.

Quantifiable morphological characteristics were followed for arthropod taxonomy identification. Formicidae and Collembola were not quantified, only the presence/absence record was taken due to their abundance.

Four sweep net samples were taken in Agroecological and Industrial sites and La Isla, each consisting of 10 sweeps with a 33.2 cm diameter net. Each sweep was 1.5m pass through the groundcover foliage [23]. The sweep samples were deposited in plastic bags, transported to the laboratory, and then frozen at -20°C to kill all arthropods. Sorting, taxonomy identification, and counts of abundance took place in the laboratory.

The taxonomic groups that could not be identified in the laboratory of the Chacra Experimental Integrada Barrow (INTA-MAIBA, for example, Diptera) were sent to the Entomology

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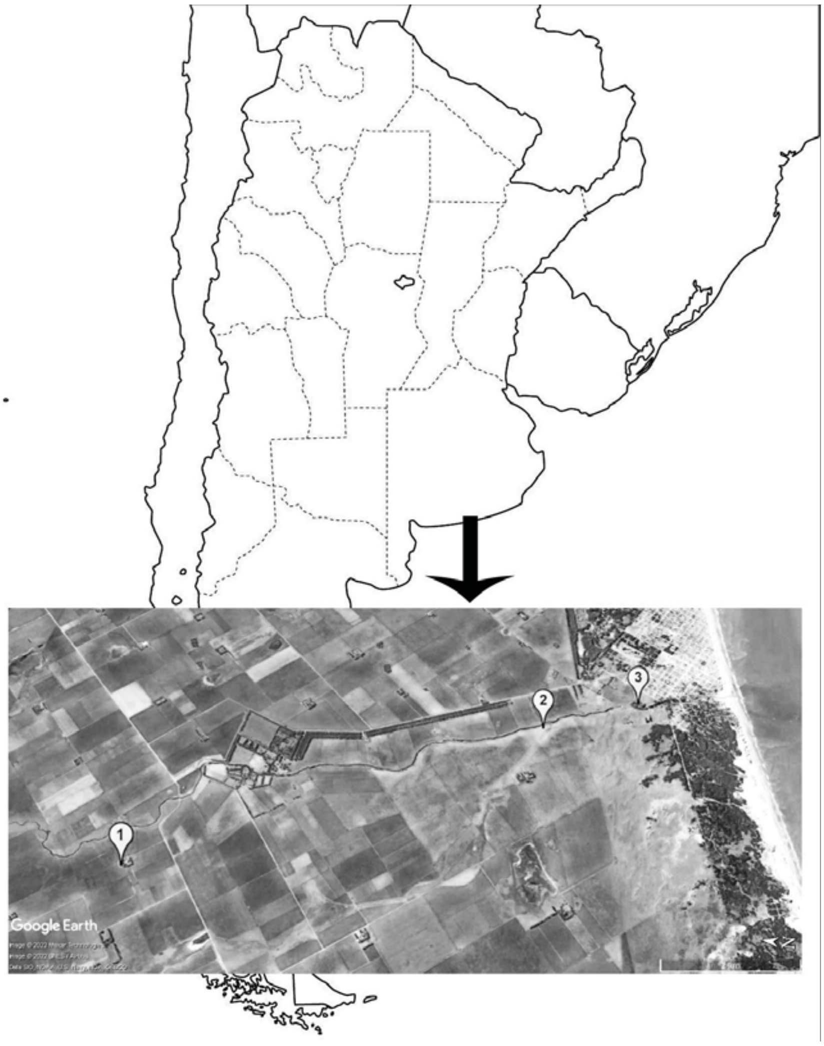

Figure 1: Map with the study areas. 1-Argelanda (S 38° 19.453´, W 60° 15.284´), 2- INTA-MDA (S 38° 48.456´, W 60° 06.014´); and 3- La Isla (S 38° 50.793´, W 60° 05.241´).

Laboratory of the IADIZA-CCT Mendoza, CONICET, to be determined. Then, the recorded species were divided into different trophic guilds, such as herbivorous, granivores, insectivorous, omnivore, carnivorous, and nectarivorous using bibliography [24-28] (**Appendix 1**).

The results of arthropods were only used for the analysis of the Trophic graph, establishing their interrelations.

Vegetation sampling

Before vegetation sampling, a field reconnaissance visit of the study area enabled the distribution of the main vegetation units to be identified from field observation. A total of 6 quadrats were sampled at each study site. The size of each quadrat was 1 m x 1 m, determined using the minimal area concept. The quadrats were placed within homogeneous vegetation sites, following the Zürich-Montpellier School of Phytosociology method [29]. The presence and abundance (cover) of species per plot (census) were estimated in percentage terms [30-33]. The position of the quadrats was determined using a Global Positioning System.

Species identification was made following Cabrera y Zardini [34], Dimitri [35], Lamberto, et al. [36], Zuloaga, et al. [37] y Villamil y Martínez [38] (**Appendix 1**).

The results of vegetation were only used for the analysis of the Trophic graph, establishing their interrelations.

Indexe

Specific richness was calculated as the number of species of mammals and birds per group, of the different functional groups (herbivorous, granivores, insectivorous, omnivore, carnivorous, nectarivorous) at the sites studied [39]. The Standardized Shannon index was obtained to measure the diversity of species, considering their uniformity, this index being standardized allows comparison between different systems. This index is normally represented as H´St. Jaccard´s Index [40] was calculated to determine the similarity between study sites (very high 80-100%, high 60-79.9%, average 40-59.9%, low 20-39.9%, and very low 0-19.9%).

Analysis of variance (ANOVA) was used to compare the abundance and specific richness (R) of the different functional groups (herbivorous, granivores, insectivorous, omnivore, carnivorous, nectarivorous) among the sites studied. Post-hoc

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testing (Tukey test, $P<0.05$ and $\alpha=0.05$) was used to test for differences among considered variables.

The Agroecological Diversity Index (I Agro) proposed by Griffon [41] was also calculated. This index allows the evaluation of the system as a whole because, in addition to measuring the richness and abundance of the elements of the system, it also takes into account its interactions. The Agro I index allows for to evaluation of the attributes of agrobiodiversity, impossible to study through the use of classical ecological indices [41]. It is also consistent with the theoretical framework of agroecology and the index structure is extremely simple and its calculation is done using the R software [42] for the analysis of networks and data in Pajek format.

Initially, each study site, considered a complete system, was represented in a graph, establishing the components of agrobiodiversity and their interrelations, that is, each species of registered bird and mammal was represented as an element of the system. Trophic groups of arthropods and vegetation strata were represented as nodes, and the nodes were related according to the main diet of each bird or mammal [43]. The nodes represent populations of species and links are the direct trophic interactions [43].

The three measures necessary to obtain the I Agro of each study site were calculated: the standardized Shannon index (HST) [40]; the density of the links (D) determined as the number of links observed in the graph thus incorporating the number of interactions in the system [44]; and the clustering coefficient (C) that relates the presence of short loops within the graph [44] that allows inferring the redundancy of the system and its functional structure. These measurements were calculated with the statistical software R [42].

Then:

$$I\ Agro = H'St + D + C$$

Since all components of the index are standardized (their maximum value is 1), the maximum value of the Agro I index is 3 [41,43].

Results

The greatest species richness and the diversity of species (H´St) were found in SNat. The density of individuals per hectare was higher in SNat and also in agroecological pastures (AEP). According to the Jaccard index, the similarity is very low between sites, only 15% (Table 1).

Only in SNat were recorded the six functional groups (including mammals and birds), while in industrial pastures (IndP) and agroecological pastures (AEP) was registered five of the six functional groups, lacked only the nectarivorous. In the wheat fields with industrial management (IndW) and agroecological (AEW), functional groups of herbivores and nectarivorous lacked (Figures 2,3).

Herbivores were more abundant in AEP, due to a higher number of European hares. The granivores were more abundant in SNAT, corresponding only to the birds. In IndW, 50% of the granivores corresponded to birds, and the other 50% to the rodent *Calomys laucha*. In AEP, the granivores were represented only by birds. Insectivores were more abundant in AEP and

Table 1: Specific richness (R), total number of individuals (N), density (N Ha^{-1}), observed Shannon indices (H´) and standardized (H´st), Jaccard (J). Graph density (D), clustering coefficient (C) and the agroecological diversity index (I Agro) including data of mammals, birds, arthropod and vegetation samplings for the sites studied.

Productive appoach	Vegetation	R	N	N/ha	H´	H´st	J	D graph	C	I Agro
Industrial	Wheat	20	163	6.4	0.98	0.690	15	0.545	0.260	1.495
	Pasture	16	142	5.6	0.68	0.567		0.540	0.381	1.488
Semi-natural	Mixed pastures	32	226	14.7	1.21	0.796		0.516	0.292	1.604
Agroecological	Wheat	18	223	8.8	0.67	0.545		0.696	0.409	1.650
	Pasture	20	288	11.3	0.81	0.614		0.520	0.319	1.453

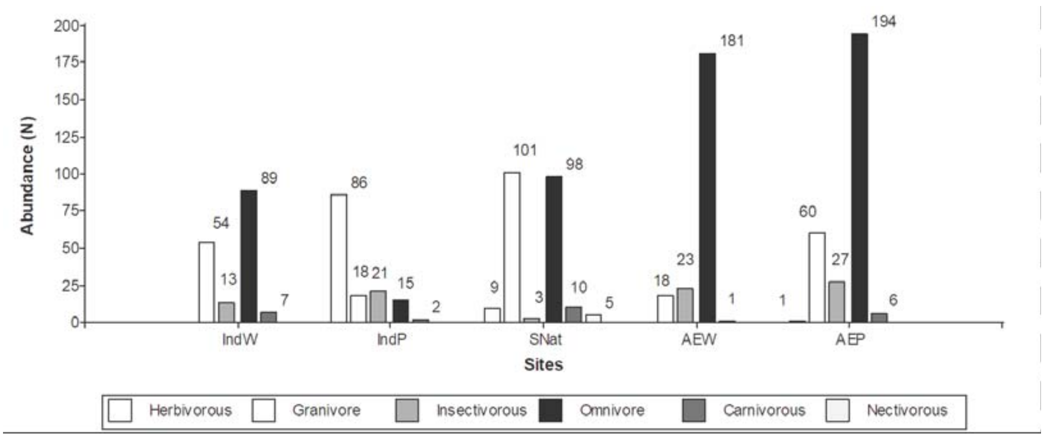

Figure 2: Abundance (total number of individuals per group includes mammals and birds) of the different functional groups (herbivorous, granivores, insectivorous, omnivore, carnivorous, nestivorous) at the sites studied. IndW (Industrial wheat); IndP (Industrial pasture); AEW (Agroecological wheat); AEP (Agroecological pasture); SNat (semi-natural area).

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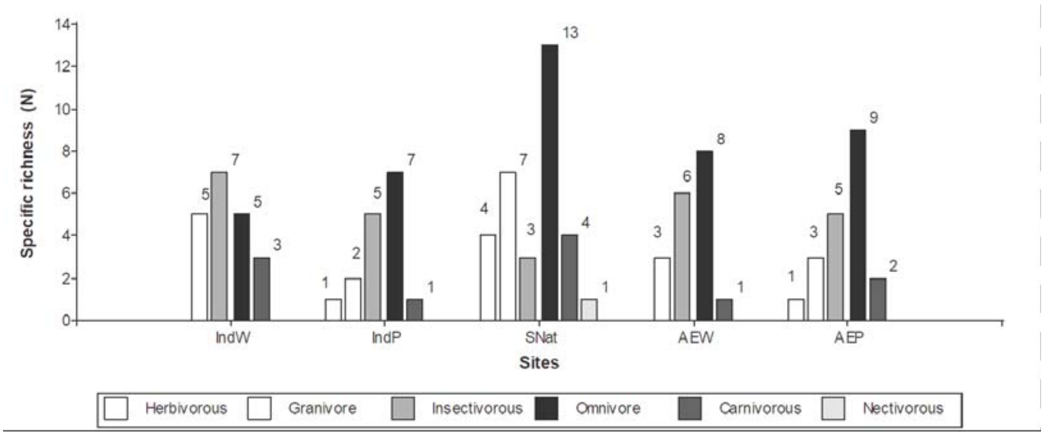

Figure 3: Specific richness (number of species of mammals and birds per group) of the different functional groups (herbivorous, granivores, insectivorous, omnivore, carnivorous, nestivorous) at the sites studied. IndW (Industrial wheat); IndP (Industrial pasture); AEW (Agroecological wheat); AEP (Agroecological pasture); SNat (semi-natural area).

AEW, decreasing in IndP, being all birds in this functional group. These results could be due to the non-use of pesticides in agroecological fields. The omnivores were more abundant in EAP, IndP, and AEW, the records correspond mostly traces of armadillos (Cingulata Order). The largest number of carnivores was recorded of SNat ($F= 6.24$; $p= 0.0005$, $gl= 6$) (Figure 2).

Likewise, the greater species richness in the functional groups of herbivores, granivores, and omnivores was observed in SNat (mammals and birds included). ($F= 13.29$; $p <0.0001$, $gl= 6$) (Figure 3).

In the graphics, we can see that the highest link density was registered in AEW, with 23 nodes; among mammals, birds, types of vegetation, and groups of arthropods. Also, the clustering coefficient was higher in AEW, where occurred 41% of the possible triangles are given. This percentage provides information on the functional structure of the system. In addition, the highest I Agro also occurred in AEW followed by SNat (Table 1, Figure 4).

Discussion and conclusions

The results show that agricultural intensification produces a loss of biodiversity detected through the richness, density, and Shannon standardized index; and the absence of herbivores (birds and mammals) and nectarivores (birds). Within the agricultural establishments, agriculture generated a simplification of the plant communities within the productive lots by moving from polyculture to monoculture, as well as by intensifying the control of weeds and arthropods of pests through the increasingly intensive use of agrochemicals [45-47]. This abusive use of pesticides generated the resistance of a part of pests and weeds, thus generating an even greater increase in the use of agrochemicals for their control [48,19], for example, controllers of insects and insectivores birds and mammals. In this way, the systems became increasingly vulnerable, because natural enemies are eliminated and pests appear that are increasingly difficult to control with the current practices [50,51]. In a conventional monoculture, the system is explicitly designed and managed to reduce as much as possible the unplanned associated biodiversity (typically by using insecticides, herbicides, etc.). Paradoxically this may contribute (among other things) to the long-term establishment of phytophagous organisms in the system, eradicating at the same time their biological controllers (Jonsson et al. 2015; Landis, Wratten, and Gurr 2000; Levins and Vandermeer 1990). In this type of farming system, most species are related directly to one (the monoculture) by a victim-exploiter relationship (i.e., predation, parasitism, parasitoids, and herbivory), where the monoculture species (the crop) typically plays the role of the victim. So, the system has a star-like architecture (i.e., many nodes connected to a central hub) with the monoculture in the center (Griffon and Torres-Alruiz 2008), which is a structure that favors the occurrence of pest situations and crops losses [43].

As shown by the high indexes of link density and the coefficient of grouping between species (mammals, birds, type of vegetation, and arthropod groups), agricultural production under the agroecological approach. This would indicate that the agroecological system generates a greater degree of cohesion and integration between the components of the system in relation to the other situations studied. These values are associated with systems that self-regulate and have closed trophic cycles. Diversity plays a significant role in maintaining the resilience of ecosystems [52], giving it the ability to adapt to disturbances, reorganize and sustain itself over time [53]. There are different trophic groups and a large number of species within them [51,54]. For example, pollinators fulfill a specific function and can be represented by bees, bats, and birds, among others [55]. Therefore, the characteristics such as the abundance in a community are one of the main determinants of ecosystem functioning [9,10].

The highest index of agroecological diversity was presented in the agroecological wheat field followed by the seminatural site. demonstrating that the key to achieving sustainable but at the same time productive agroecosystems is the application of the agro-ecological productive approach, through which biodiversity landscapes are obtained, including productive

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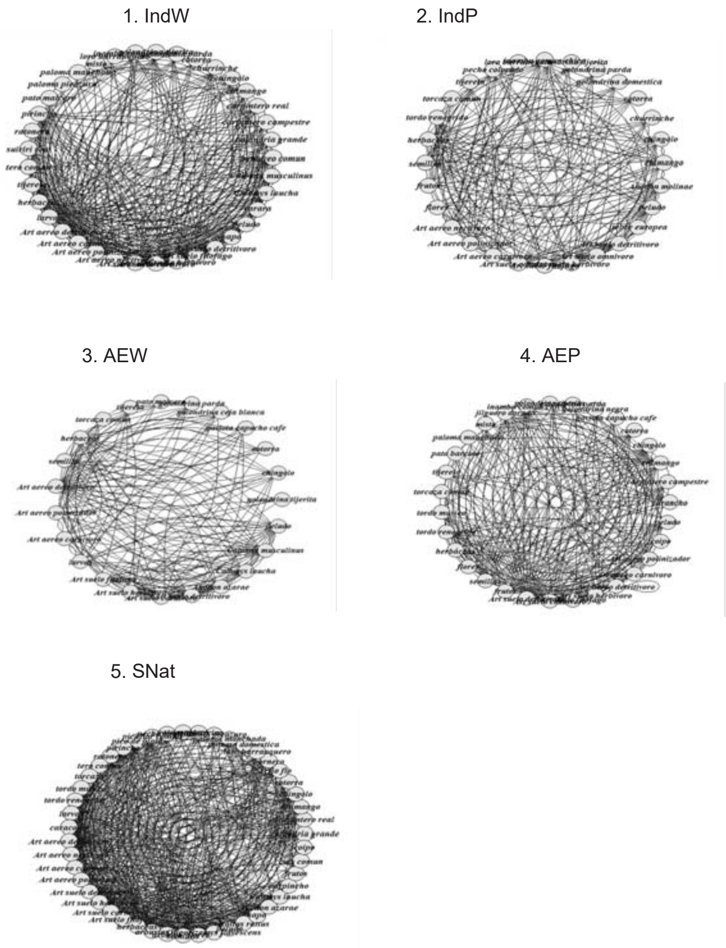

Figure 4: R Graph´s represents the ecological networks of each study site. The nodes represent populations of species and links are the direct trophic interactions. 1. IndW (Industrial wheat); 2. IndP (Industrial pasture); 3. AEW (Agroecological wheat); 4. AEP (Agroecological pasture); 5. SNat (semi-natural area).

diversity (crops and animals), as well as auxiliary and functional biodiversity [56]. This demonstrates that the key to achieving sustainable but at the same time productive agroecosystems is the application of the agro-ecological productive approach, through with biodiversity landscapes are obtained, including productive diversity (crops and animals), as well as auxiliary and functional biodiversity, such as agroforestry systems (SAF) by creating patches and corridors [56]. Incorporating woody or shrubby species into the results of the system in numerous ES, especially in those ecosystems where the tree or species are part of the original structure of the place. It favors the maintenance of soil fertility, minimizes erosion, and gives shelter and food to various species [57]. For the spatial heterogeneity to have a positive effect on the internal dynamics of agroecosystems it is necessary, on the one hand, for an inside farm design that attracts biological controllers (e.g., flower strips or beetle banks) (Altieri, Ponti, and Nicholls 2005; Nicholls and Altieri 2002) and on the other, the existence of nearby sources of organisms with enough internal complexity to provide the necessary control agents (Rusch, et al. 2016, 2010; Tscharntk, et al. 2012). Thus, spatial heterogeneity may enhance the configuration of the complex ecological networks needed for a successful ecological pest management program (Batáry, et al. 2011; Fahrig, et al. 2011; Rusch et al. 2016, 2010; Tejat, et al. 2002; Tscharntke, et al. 2002, 2012).

Ecosystem services derive from ecological processes that are, to a large extent, a consequence of the organisms that inhabit them, so it is vital to study and promote the conservation of biodiversity [58,59]. Ecosystem services lead to increased human well-being [1,60]. These include: i) natural assets or resources such as water or food, ii) the processes that regulate the conditions in which humans live, such as climate or erosion regulation, iii) experiences that directly benefit or indirectly to societies, such as the sense of belonging or recreation, and iv) the basic ecological processes that allow the previous ones to be provided [61,62]. Then the conservation of biodiversity is important because agricultural production depends on the vital ES it provides and because it also ensures stability and resilience, that is, the ecosystem's ability to recover after external stress.

Based on the results obtained, it is concluded that it is necessary to study biodiversity, not only the richness and abundance of plant and animal species but also include the relationships that occur between them [7,8,41,63] as well as the ecosystem services that derive from them and their interrelations. An important type of interaction between the components of an agroecosystem is the non-linear trophic relationships that determine the stability of the populations present [41,64]. The use of simple and practical indicators is

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vital to provide technicians, producers, and politicians with reliable and understandable information about the impacts and costs of incorporating different productive approaches [65-67].

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