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# Silvopastoral and peasant management effects on vegetation and soil quality in the arid chaco of central Argentina

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ABSTRACT

Nowadays the arid Chaco in central Argentina presents gradients of woody vegetation cover with a variety of management regimes with different environmental impacts. Here, we compare the relative effects of the two most widespread management systems in the region: silvopastoral and peasant managements. Soil properties, plant species richness, composition and vegetation structure were used as ecological indicators as they are crucial for long term-sustainability of production systems. Vegetation cover and plant composition responded differently to land management systems. While plant species richness and composition remained similar in both land management types, tree cover showed a strong reduction in silvopastoral systems. We also observed differences in soil properties, with increases in nitrates, sulfates and electrical conductivity in silvopastoral systems as compared to peasant land management. Tree cover reduction and higher soil salinity may impact negatively the productive capacity of soils, which may compromise the delivery of ecosystem services in silvopastoral systems of central Argentina in the long-term. Peasant land use management showed comparable less environmental impact on soils, allowing the preservation of not only provision services but also of regulating and supporting services in these highly vulnerable areas.

## 1. Introduction

The Great Chaco in South America holds one of the most extended seasonally dry subtropical forests of the world (Bucher, 1982). These forests have experienced an extensive and intense loss over the past few decades reaching one of the highest deforestation rates worldwide (Viglizzo et al., 2011; Buchadas et al., 2022). In Argentina, the replacement of Chaco forests by different productive systems is widespread and still increasing throughout the territory without multi-scale planification and straightforward state intervention (Frate et al., 2015; Marinaro et al., 2020). In the semi-arid Chaco regions of Córdoba, land use changes were triggered by the increase in annual rainfall during the 1950–2000 period, the rising global demand for grain production, and the introduction of transgenic crop cultivars (Hoyos et al., 2013; Buchadas et al., 2022). These coupled factors allowed cultivation with acceptable yields of primary transgenic soybean under zero tillage management in the region (Zak et al., 2008). In contrast, in the arid north and northwest Chaco regions of Córdoba, rainfall is much lower and precipitation regime has not changed, thus crop production is not possible without irrigation (Zak et al., 2008). In these arid regions, deforestation has been mainly associated with pasture implantation and increasing livestock production (Zak et al., 2008; Viglizzo et al., 2011; Hoyos et al., 2013; Frate et al., 2015; Buchadas et al., 2022).

Currently, the arid Chaco of Córdoba presents gradients of different woody vegetation cover (open forests and shrublands) along with cattle production systems operating under a variety of management regimens (Hoyos et al., 2013; Fernández et al., 2020). One of the most widespread in the region is the silvopastoral management system, which initially removes all the woody vegetation leaving only large trees standing. To remove the vegetation, tractors with heavy cylinders (i.e., roller choppers) equipped with transversal blades are used to chop and crush all small- and medium-sized woody vegetation. This practice aims to create a park-like vegetation structure that allows cattle accessibility and it is generally complemented with exotic megathermic grass cultivation

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(Kunst et al., 2003). Silvopastoral systems are typically associated with intensive livestock breeding and large-scale livestock establishments (Cáceres, 2015). Another historically widespread production regime in the region is the peasant management system (Cáceres, 2015; Fernández et al., 2020). This type of land management makes multiple uses of the forest, exploiting timber and non-timber resources along with livestock breeding, primary goats. Peasants' livestock management is extensive and their animals feed mainly on the native foraging fruits, buds, and leaves (Cáceres, 2015). Notably, land use by local peasant communities is currently retracting within this arid region due to the growing demand for large-scale grazing areas by private entrepreneurs, who have advanced into territories historically occupied by peasants with no formal tenure of the land (Altrichter and Basurto 2008; Cáceres et al., 2010; Fernández et al., 2020). This process has contributed to an exclusion of local communities from their lands, restricting the access to basic and important ecosystem services that the forest provides (Cáceres, 2015; Marinaro et al., 2020).

Despite the widespread presence of these two types of land management systems in the arid Chaco, no study to our knowledge has yet compared their relative effects on the environment. Soil quality and plant species composition and vegetation structure are important ecological indicators about environmental status among productive systems, and thus about their potential long-term sustainability. Currently, the knowledge regarding the effects of land management on vegetation and soil quality in the arid Chaco is biased towards evaluating the effects of different types of silvopastoral systems (differing in age, presence of exotic pastures, prescribed fires, etc.) using untreated areas of native forest as controls (e.g., Anriquez et al., 2005; Kunst et al., 2012; Rejzek et al., 2017; Steinaker et al., 2017; Lumbreras et al., 2019). Several studies showed that short-term effects of roller choppers change the dominance of plant functional groups or life forms, favoring herb and grass cover. Despite this reported structural changes on vegetation, not large changes have been observed in the overall native vegetal composition (Blanco et al., 2005; Kunst et al., 2012; Rejzek et al., 2017). After 3–4 years of roller chopper application, shrubs resprout and appear to recover a large percentage of their initial cover while herb cover tends to decrease. In contrast, tree cover has little recovery over time and thus it would be the most affected strata (Kunst et al., 2012; Steinaker et al., 2017).

Studies assessing the effects of human land use changes on soil quality in the arid Chaco region are scarce. A couple of studies show an overall decrease in soil quality with higher land use and grazing intensity (Abril and Bucher, 1999; Conti et al., 2016). In highly overgrazed sites, organic carbon, soil moisture and total nitrogen decreased whereas bulk density and electric conductivity increased (Abril and Bucher, 1999; Conti et al., 2016). More specifically, short-term effects of silvopastoral management systems showed no significant changes on soil organic carbon (Anriquez et al., 2005). However, in the long-term (16 years), silvopastoral management increased soil organic carbon, possibly because of the incorporation of vegetal waste produced after roller chopper application (Lumbreras et al., 2019).

The aim of this study is to compare the relative effects of the two most widespread productive systems in the arid Chaco, silvopastoral and peasant managements, on plant species composition and the relative cover of different life forms as well as on the quality of soils in central Argentina. Based on the evidence regarding the effects of silvopastoral management on native vegetation, we test the following hypothesis: (1) silvopastoral management system does not significantly change plant species diversity, richness, and composition in comparison with the peasant management but (2) it does change vegetal structure mainly by decreasing tree cover. Finally, because silvopastoral systems present a more intensive land use regime associated with the use of roller choppers and larger stocking density, we hypothesize that (3) silvopastoral management reduces soil quality relative to peasant management system.

## 2. Materials and methods

### 2.1. Study area

The study was conducted in the Sobremonte Department, in the north of Cordoba province. This area belongs to the driest expression of the Great Chaco forests with a strong hydric deficit due to the high mean temperature (34 °C) and low mean precipitation (300–500 mm) during the summer growth season (November–March). The upper layer of the original vegetation reaches up to 10 m height and is constituted by the dominant trees *Aspidosperma quebracho-blanco*, *Prosopis flexuosa*, *Prosopis torquata*, *Sarcomphalus mistol* and the cacti *Stetsonia coryne*. The shrub layer varies between 3 and 4 m height with *Mimozyganthus carinatus*, *Larrea divaricata*, *Senegalia gilliesii* and *Parkinsonia praecox* as the dominant species. Within an area of 14 km$^2$ (29° 27′ 38'' S, 64° 14′ 47″ W and 29° 34′ 51'' S, 64° 18′ 36″ W) we selected 12 plots of 500 m$^2$ (50 × 10 m), located in four different sites (3 plots per site) separated by > 1 km in two contrasting land-management types: Six plots were located in sites with peasant management of land and six plots were located in areas subjected to silvopastoral systems in large agricultural establishments (Fig. 1). Peasant management plots presented traditional production systems with natural forage provided by native woodlands. In this system the primary type of livestock was goats with low stocking density (between 0.04 and 0.09 animal unit equivalent; estimated by data obtained from information provided by land managers). The more industrialized silvopastoral management parcels had the last roller chopper applied 5–8 years ago. These production systems use large areas with medium to high cattle stocking density (between 0.2 and 0.4 animal unit equivalent; estimated by data obtained from information provided by land managers) and the main feed for cattle comes from implanted pastures with exotic grasses (Fernández et al., 2020). Here, we did not have control sites of well-preserved arid Chaco forests because there is none in the area. Our focus was to compare the relative effects of the two most widespread land-management types. In order to make sure that all sites were comparable we measured soil texture in the 12 plots. All soil samples shared the same geomorphological origin and thus the same taxonomical cartographic unit (DGut-4), which are categorized as sandy loam soils, poor in organic matter, low moisture retention capacity and moderate salinity (INTA, 2006; see Tables S1 and S3).

### 2.2. Vegetation and soil sampling

In April 2019 we conducted a systematic sampling of the vegetal community in each of the 12 selected plots. We recorded the complete floristic composition in a plot of 500 m$^2$ (50 × 10 m), in order to quantify total, and per stratum (herb, shrub and tree) plant species richness. The nomenclature and taxonomy of the recorded plant species and their categorization in different life forms (herb, shrub and tree) was based on Flora Argentina (http://www.floraargentina.edu.ar/). Moreover, we assigned to each plant species one of the following cover-abundance categories: <1%, 1–5%, 6–25%, 26–50%, 51–75%, and >75% (Braun-Blanquet, 1950). These records of plant richness and abundance were used to estimate diversity and composition. Overall percent cover of arboreal, shrub, and herbaceous strata as well as bare soil were also estimated with observational approximation at each sampling plot. Three operators conducted the surveys at each sampling plot: while two of them walked along the sampling plot surveying all vascular plant species present within 10 m width, a third operator took notes on their observations. Specimens of all sampled species that were not possible to identify in the field were collected and deposited in the Botanical Museum herbarium of the National University of Cordoba (CORD) for taxonomic classification.

To assess soil quality, we collected three soil samples (0–10 cm of depth) randomly located within each plot. These samples were placed in double plastic bags and stored in a portable Styrofoam cooler to avoid soil dehydration in the field. Samples were weighed immediately after

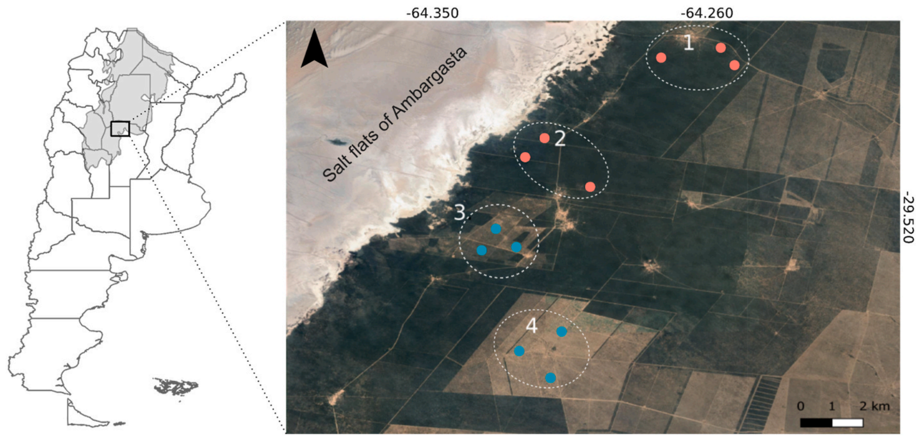


**Fig. 1.** Spatial location of the sampling plots in the arid Chaco Forest of Central Argentina. The gray area in the map represents the Argentine Chaco region and the black rectangle the study area in Córdoba province. Blue circles indicate silvopastoral management and red circles indicate peasant management system. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

collection to obtain gravimetric soil moisture. In the laboratory, they were placed in a drying oven at 60 °C until the sample reached a constant weight. Soil water content (%) was calculated as the ratio between water weight (g) and dry soil weight (g). Subsequently, we made a single composite sample from the 3 samples per parcel, and took them to the Soil and Water Laboratory of the Faculty of Agronomic Sciences, National University of Córdoba. The following soil parameters were analyzed: (i) organic matter (OM, %); (ii) organic C (%); (iii) total N (%); (iv) CN ratio; (v) $NO^3$ (ppm); (vi) extractable P (ppm); (vii) sulfates (SO4 2, ppm); (vii) current pH; and (ix) electric conductivity (EC, dS/m). The analyses were carried out according to: (i) organic C by the Walkley–-Black wet digestion method; (ii) total N by semi-micro Kjeldahl; (iii) $NO^3$ using ion selective electrodes; (iv) extractable P by the Bray–Kurtz method and (vi) electrical conductivity (EC; 1:1, soil: water ratio). Soil organic carbon data were multiplied by a factor of 1.72 to give soil OM values (Howard and Howard, 1990).

### 2.3. Data analysis

All the analyses described below were performed in the R environment (R Core Team, 2020). We analyzed the sample completeness between both land management types with a non-asymptotic approach based on rarefaction and extrapolation of incidence data for standardized samples with iNEXT package (Hsieh et al., 2020). We used linear mixed models to analyze whether species richness and vegetation cover (% tree, shrub and herb cover) differed between land management types. We used land management as the fixed effect with two levels (silvopastoral *vs* peasant), and site as a random factor. We used Poisson error distribution to analyze species richness, and binomial error distribution to analyze percentage of vegetation cover (herb, shrub and tree) and bare soil. All the linear mixed models were run using the glmer function of the lme4 package (Bates et al., 2015). Finally, we calculated Shannon's diversity indexes using abundance species data for each plot and analyzed them with a linear model *(*package *stats)*.

The significance of the fixed factor on species richness and vegetation cover was tested by likelihood ratio test, LRT. Prior to the execution of these models, the assumptions of normality of residues and homogeneity of variances were proven for the correct interpretation of the results. We estimated overdispersion by calculating the parameter of scale,ˆc = Σ(Pearson residu-als2)/degrees of freedom. Overdispersion was found in models testing the percentage of vegetation cover; this lack of homogeneity of variances between conditions was corrected by using the "quasibinomial" family.

To compare the similarity in species composition between conditions we built a matrix with values of Bray-Curtis distance from abundance species data of each sampling plot differentiated by strata (herb, shrub and tree). Based on this, we conducted a one-way non-parametric similarity analysis, ANOSIM (with 999 permutations), to determine whether species composition differed between land management. Also, we performed NMDS (Non-Metric Multidimensional Scaling) ordination analysis using the calculated dissimilarity measures to visually assess differences in species composition between management types. This graphical output shows similarity in species composition among parcels, whereby the closer they are ordinated the more similar their composition. We calculated the stress value that represents the difference between distance in the reduced dimension ordination and the complete multidimensional space, thus, it reflects how well the ordination summarizes the observed distances among the parcels. According to Clarke (1993), a stress value lower than 0.1 gives a "good ordination with no real risk of drawing false inferences". These analyses were run using the *vegan* package (Oksanen et al., 2016).

Soil quality parameters were analyzed with non-parametric statistical tests, as the homogeneity of variance assumption was not achieved and model fit was not good enough with mixed linear models. We calculated the mean difference of soil properties (Organic matter, organic carbon, total nitrogen, phosphorus, nitrates, sulfates, electrical conductivity and soil moisture) between peasant and silvopastoral land management. These mean differences express the magnitude and direction of the effects and were depicted as Gardner-Altman plots (*dabest* package, Ho et al., 2019). Mean differences were calculated by subtracting the mean value of a soil property between peasant and silvopastoral management (Peasant minus Silvopastoral). Therefore, positive differences imply higher mean value of the soil property in the peasant land management whereas negative differences imply higher mean values in the silvopastoral management.

## 3. Results

### 3.1. Vegetation

The completeness of the vegetal sampling was similarly high (>90%) between both land management systems (Fig. S1), implying that both the size of the sampling plot (500 $m^2$) and the number of sampling plots per land management type were appropriate to detect the vast majority of species. We found a total of 79 plant species (26 families) across all parcels in the two management systems (Table S2). We registered 64 species in the peasant management and 60 species in the silvopastoral management. Most plant species were native (75 species) and 16 of them were endemic to Argentina. Only 4 species were non-native and belonged to the Poaceae family (*Cenchrus ciliaris, Megathyrsus maximus,* *Panicum coloratum* and *Urochloa trichopus*). The mean plant species richness of all life forms, as well as for herbs, shrubs and trees were similar in both management types ($Z < 1.49$, $P > 0.13$, Fig. 2). In line with these results, the Shannon's diversity index was similar between land use conditions (T = 1.13, P = 0.28).

Herb, shrub and tree species composition were similar between management systems ($R^2 < 0.24$, $P > 0.08$, Fig. 3). In all cases, the stress value was low (S < 0.10), which means NMDS provided a good representation of the observed distances among the plots with two dimensions in the multivariate scale. In NMDS graphics, plots under different management systems are overlapped between them, meaning they both share several species. Despite such similarity, it is interesting to note that tree species composition showed a more widespread distribution among silvopastoral sites compared to the peasant sites.

Herb and shrub cover tended to be higher in the peasant management, but this difference was non-significant. The cover of the arboreal stratum presented a significant reduction of 50% in silvopastoral management compared to peasant management (Table 1). Finally, the percent cover of bare soil was significantly higher in the silvopastoral management (Table 1).

### 3.2. Soil

The mean differences in organic matter, organic carbon, total nitrogen, moisture, CN ratio, pH and phosphorus, between peasant and silvopastoral management systems were positive, implying their mean values increased in the peasant management in relation to the silvopastoral system. These differences, however, were non-significantly different from zero (Table 2). In contrast, the mean differences in nitrates, sulfates, and electric conductivity were large, negative and significantly different from zero, indicating they strongly increased in the silvopastoral management system (Table 2). Values of soil properties from each site are presented in Table S3.

## 4. Discussion

In this study we assessed two fundamental ecological dimensions – vegetation and soil quality – in two widely spread land management systems of the arid Chaco represented by different social actors. These types of studies are scarce in the region but particularly important as a great part of the Chaco forests has been converted into agricultural and pasturelands and this trend is likely to continue (Viglizzo et al., 2011).

As we initially hypothesized, plant species richness, diversity and composition were similar between both land use management systems. These results suggest that the diversity and composition components of the vegetal community of the arid Chaco are relatively resilient to grazing and roller chopper application. A similar trend has been reported in studies conducted in silvopastoral areas in other regions of the arid Chaco, where plant diversity and composition remained similar or it was barely affected compared with untreated areas short after roller chopper application (1–5 year; Blanco et al., 2005; Kunst et al., 2012; Rejzek et al., 2017). These result patterns may be explained by the great resprouting capability and the high local persistence of native species of the arid Chaco after disturbances such as logging, herbivory, and fire (e.g., Lipoma et al., 2020; Jaureguiberry et al., 2020). Similarities in vegetal composition and diversity between both management systems also suggest that higher-density cattle livestock, which predominate in silvopastoral systems, have equivalent effects on these vegetation properties as lower-density goat livestock in the peasant management system. However, higher-density cattle livestock of silvopastoral systems comes with the cost of higher bare soil as observed here, increasing the probabilities of soil erosion and compaction (Greenwood and McKenzie, 2001). Silvopastoral management presented higher variability in tree species composition among plots than the peasant management, suggesting that different site-specific silvopastoral strategies may introduce higher heterogeneity to tree species composition. It has been observed that roller choppers introduce heterogeneity in the system as they may increase woody beta diversity (Rejzek et al., 2017). This effect was explained by the variability in the resprouting vigor of the damaged woody plants that causes differences in the recovery rate of native species, the uneven intensity in roller chopping and variability in site conditions (Rejzek et al., 2017). In contrast, peasant plots were more homogeneous in tree species composition, possibly because the stable woody state of the forest was not as heavily disrupted.

As expected, vegetal structure was affected and the arboreal stratum cover was significantly reduced by the silvopastoral management system. Such reduction may decrease the abundance of forage resources for livestock from rich-nutrient fruits and leaves of dominant trees such as *Prosopis* spp. and *Sarcomphalus mistol.* These species produce very large quantities of fruits with high content of sugar, protein and minerals, representing a suitable fodder resource that can meet grazing requirements of livestock, as has been observed in *Prosopis chilensis* (Abdalla et al., 2014). In line with this, other authors have reported a forage impoverishment of silvopastoral systems due to the loss of tree forage species such as *Prosopis* spp. and the increase of species with non-forage value (Steinaker et al., 2017). Also, tree cover reduction in the silvopastoral system may have negative consequences for ecosystem functioning. Increased tree abundance improves a wide range of other ecological functions, such as higher soil nutrients availability, bacterial diversity, and forest structural complexity, as well as the provision of habitat and resources for pollinators and seed dispersers (e.g., Jackson and Ash, 2001; Requier and Leonhardt, 2020).

We did not find significant differences in most of the soil quality parameters, but they tended to be higher in peasant sites. Thus, the third hypothesis is not entirely rejected. Organic matter, organic carbon, total nitrogen, phosphorus and soil moisture are usually positively related to vegetal organic matter input and vegetal cover (Chapin et al., 2002). The C:N ratio is related to organic matter, nitrogen concentration and soil moisture. Thus, the similar values found in these soil properties in both management systems could be explained by the compensation between the loss of woody vegetation cover and an increased input in vegetal waste as a product of the roller chopper use in silvopastoral systems (Adema et al., 2004).

We also found higher content of nitrates in silvopastoral sites which suggests a higher soil nitrification rate. Enhanced nitrification in response to grazing pressure has been reported in different unfertilized grassland ecosystems (e.g., Meyer et al., 2013), as the presence of herbivores tends to accelerate nitrogen cycling (Chapin et al., 2002). Increased nitrification rate could be explained by different factors such as urine and dung input by cattle (Petersen et al., 2004), changes in interactions between microorganisms and plants produced by grazers

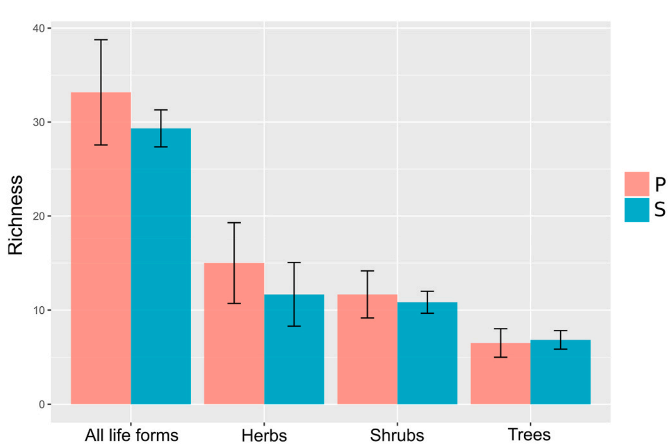


**Fig. 2.** Mean plant species richness ± SD of all life forms, herbs, shrubs and trees in peasant (P, red) and silvopastoral (S, blue) management systems. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

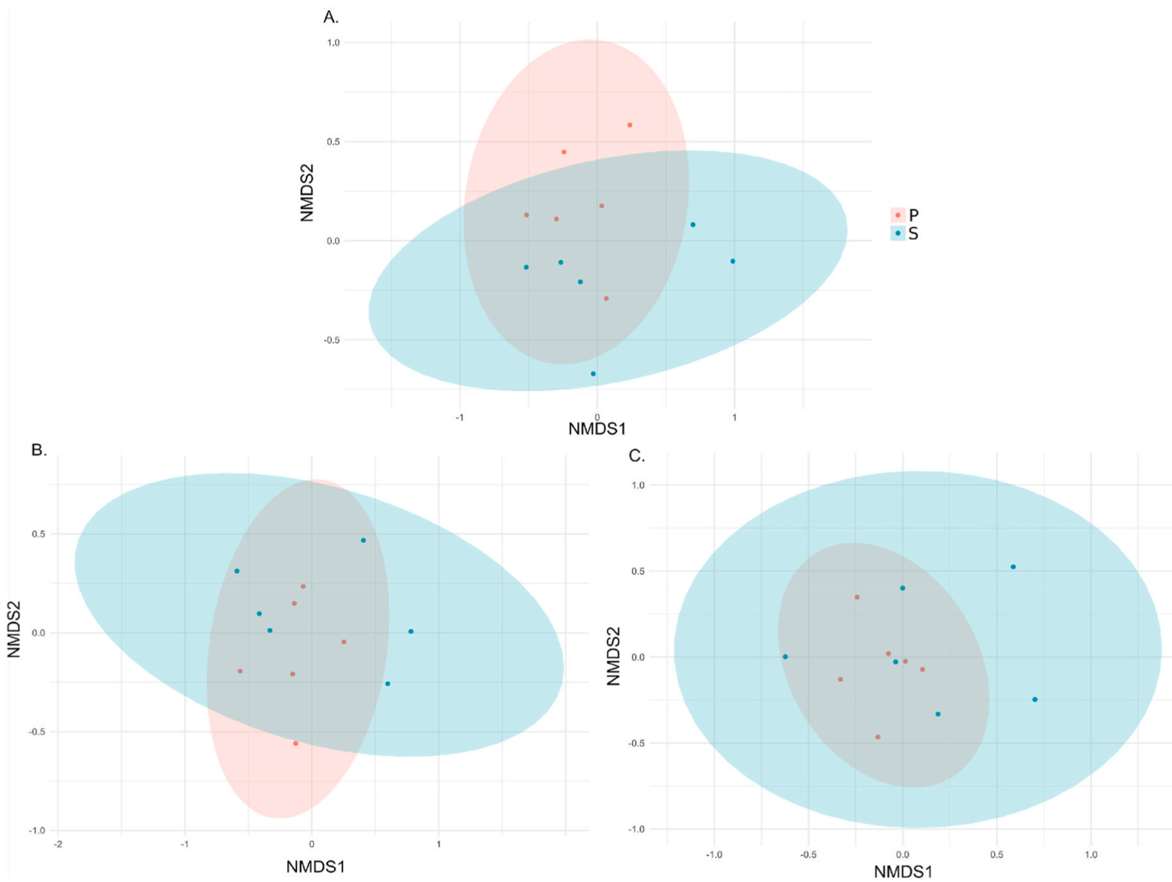


**Fig. 3.** Non-metric multidimensional ordination with vegetal species composition of (A) herb, (B) shrub, and (C) tree strata. Peasant (P, red) and silvopastoral (S, blue) management systems. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

**Table 1**
Mean relative percent cover and their standard deviation of different life forms of plants and bare soil in peasant and silvopastoral management systems.

| Cover type | Peasant management (mean ± SD) | Silvopastoral management (mean ± SD) | Statistical test |
|---|---|---|---|
| *Herb* | 56.67 ± 21.60 | 43.33 ± 29.60 | T = 0.62, P = 0.59 |
| *Shrub* | 74.16 ± 9.17 | 53.33 ± 29.44 | T = 3.21, P = 0.08 |
| *Tree* | 28.33 ± 9.83 | 14.17 ± 4.92 | **Z = 5.90, P< 0.05** |
| *Bare Soil* | 24.17 ± 12.42 | 38.33 ± 9.83 | **Z = 2.40, P = 0.02** |

**Table 2**
Soil properties mean difference effect between silvopastoral (S) and peasant (P) management systems (S - P) and 95% confidence interval [IC]. In bold are shown mean differences that differ from cero.

| Soil properties | Unpaired mean difference (P minus S) and 95% CI |
|---|---|
| Organic matter (%) | 0.435 [-0.283; 1.01] |
| Organic carbon (%) | 0.25 [-0.166; 0.583] |
| Total nitrogen (%) | 0.0165 [-0.0172; 0.0402] |
| Soil Moisture (%) | 1.22 [-0.0669; 2.56] |
| CN ratio | 0.567 [-0.15; 1.5] |
| pH | 0.133 [-0.25; 0.583] |
| Phosphorus (ppm) | −3.05 [ −8.13; 1] |
| Nitrates (ppm) | **−46.2 [ -75.2; -6.81]** |
| Sulfates (ppm) | **−13.7 [ -21.2; -5.13]** |
| Electrical conductivity (dS/m) | **−6 [-11.9; -1.95]** |

(Hamilton and Frank, 2001) and changes in the abundance and community structure of soil bacteria (Patra et al., 2005). Nitrates are the most important form of the available nitrogen for plant growth, so their increase could represent an improvement for grass production and plant biomass in silvopastoral systems (Lui et al., 2022).

Nevertheless, we also found significant higher levels of sulfates and electrical conductivity in the silvopastoral systems. Electrical conductivity, which is an indicator of soil salinity, in some silvopastoral plots reached extreme values (>16 dS/m; see Table S3). Consistently, sulfate content was c. a. 60% higher in the silvopastoral systems. Thus, the higher values of electrical conductivity in silvopastoral sites may be related to the higher content of sulfates and possibly to other soluble salts, such as chlorides. In dryland areas, salt accumulation in the soil surface is often related to the ascension of salts by capillarity from underground water when the water table rises (McFarlane et al., 2016). Native woody plants, especially trees, from the arid Chaco forests consume water intensively, preventing deep drainage of rain water to the groundwater table and keeping water table at a low level, therefore reducing the risk of soil salinization (Glatzle et al., 2020; Jobbágy et al., 2020). Soil salinization is a serious problem that mainly affects arid and semi-arid regions, because it decreases the productive capacity of the soil and alters ecosystem functionality (Williams, 1999). Also, increased soil salinity affects water availability to plants through reduction of soil water potential, reducing plant growth, plant biomass and leaf area (Munns and Tester, 2008). As a result, the increase in sulfates and electrical conductivity is likely to have negative consequences in forage production and the long-term sustainability of these silvopastoral management systems. Because the recovery of soil salinization process is unlikely in the short term (Walker et al., 1999), we underline the need to swiftly increase the monitoring of soil salinity in silvopastoral systems of the arid Chaco in central Argentina.

Peasant management system practiced by local communities has been historically invisibilized both in the scientific literature and by policy makers in the territory. Here, we observed that peasant land use management showed comparable less environmental impacts than silvopastoral management, with higher tree cover and lower levels of soil salinization, thus allowing the preservation of not only provision services but also of regulating and supporting services in these highly vulnerable areas. Sustainability involves balancing the provision of multiple ecosystem services that meet short term social needs with long term support of essential regulatory and supporting services (Chapin et al., 2009). Importantly enough, local peasant communities depend more directly on ecosystem services provided by the forest and thus they will be more affected than any other social sectors by practices that favor the degradation of the environment (Silvetti, 2011). Vegetation and soil properties show a small fraction of the complexity of agroecosystems and more studies are needed to integrate other aspects and to improve our understanding of these ecosystems, making possible to optimize management and conservation strategies with local communities.

## CRediT authorship contribution statement

**Victoria Marquez:** Investigation, Data curation, Methodology, Formal analysis, Conceptualization, Writing – original draft. **Lucas M. Carbone:** Investigation, Data curation, Formal analysis, Methodology, Conceptualization. **Ana L. Chiapero:** Investigation, Methodology, Writing – review & editing. **Lorena Ashworth:** Investigation, Conceptualization, Writing – review & editing. **Ana A. Calviño:** Investigation, Conceptualization, Writing – review & editing. **Fernando Zamudio:** Investigation, Conceptualization, Writing – review & editing. **Ramiro Aguilar:** Conceptualization, Investigation, Methodology, Writing – review & editing, Project administration, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2022.104845.

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