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RESEARCH ARTICLE

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Impacts of shrubs on soil quality in the native Monte rangelands of Southwestern Buenos Aires, Argentina

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Abstract

Shrub cover in semiarid rangelands may induce changes in soil resources and ecosystem functioning. However, it is unknown the real influence that shrub vegetation has on soil quality in rangelands used for livestock purposes. We evaluated the shrub cover effect on 12 chemical and biochemical parameters of soil quality. In a semiarid Monte rangeland of Argentina, 6 paddocks were selected and 10 m transects were placed in a patch with (Sh) and without shrubs (WSh). Then, sites with grasses (Sh-G and WSh-G), bare ground-litter (Sh-BL and WSh-BL), and under shrub cover (Sh-S) were selected. In spring 2017 and 2018, a composite soil sample (0–10 cm in depth) was taken at each site ($n = 6$). Sh-G and Sh-S sites presented high values of soil organic matter, soil organic nitrogen, particulate organic matter (POM), and cellulase activity (CA); WSh-BL and Sh-BL sites were associated with the lowest contents of these variables. For the rest of the soil quality parameters, the soil sampling sites showed similar values. These results show that woody presence should not be directly linked to soil quality loss. Although we did not detect a shrub effect in all parameters studied, in the context of appropriate grazing management, the presence of plant species of different functional groups has a positive effect on organic matter and N content of soil close to them. Moreover, in these sites, high POM values represent an important reservoir of potentially available nutrients, and promote CA necessary for fresh litter decomposition improving the soil quality of semiarid rangelands.

KEYWORDS
Argentina, microbial activity, nutrient availability, Patagonia, rangelands, semiarid environment

1 | INTRODUCTION

Rangelands are one of the most widespread plant communities in the world, occupying a fifth of Earth's surface (Estell et al., 2012). During the last 150 years, there has been an increase in shrub cover around the world (D'Odorico et al., 2012). Shrub encroachment is defined as an increase in the density, cover, and biomass of plant species with a shrub or semi-shrub growth habit, occurring in environments dominated by herbaceous species (van Auken, 2009).

Within the scientific community, there are two opposing positions on shrub encroachment effects in arid and semiarid environments. On one hand, it has been shown that an increase in shrub cover generates a more heterogeneous environment (Schlesinger et al., 1996) and creates opportunities for colonization of new shrubs because it reinforces itself as abiotic (i.e., nutrient transport and water availability) and biotic (i.e., root and microbial activity) mechanisms determine a mobilization of soil resources (Busso et al., 2010). This resource mobilization generates a mosaic of impoverished areas and promotes "fertility islands" formation around shrubs (Schlesinger et al., 1996). However, Eldridge et al. (2011) showed that an increase in woody cover was associated with decreases in grass cover and soil pH but also with increases in total organic carbon, total nitrogen, exchangeable calcium, available phosphorus, and potential N mineralization. For the first 0–15 cm soil depth, shrub encroachment increased root biomass, while the density and richness of vascular plants were not affected.

The extent to which shrub encroachment leads to soil degradation and desertification depends on functional groups of encroaching shrubs and grass species being replaced, climatic conditions, and grazing pressure (Eldridge & Soliveres, 2015; Maestre et al., 2009, 2016). Soil quality assessment is important to conserve and rehabilitate degraded environments. It is described as "the ability of the soil to maintain its biological productivity, promoting the health of plants, animals and humans" (Doran & Parkin, 1994). Soil microbiota plays a central role in soil quality because they are involved in processes that increase nutrient availability, such as humification, cycling, and mineralization of soil organic matter (SOM) (Bünemann et al., 2018). In some environments, shrub presence has created very marked differences between shrub sites and bare interspaces, altering microbial compositions and reducing fungi and bacteria diversity (Herman et al., 1995; Yannarell et al., 2014). However, other studies have reported that shrub cover increases the phosphatase, urease, and β-glucosidase activity of the soil, enhancing organic matter availability and soil fertility in semiarid environments (Maestre et al., 2011). High activity and abundance of soil microbial communities under shrubs could be related to lower temperature and radiation as a result of canopy shading (Bachar et al., 2012). In addition, increases in the production of root biomass, belowground litter, and radical exudates, together with the occurrence of hydraulic rise in woody species, would be responsible for the effects observed (Maestre et al., 2009). Global scale studies in different semiarid environments suggest that multiple ecosystem functions, which include different soil quality parameters, are maximized at moderate levels (close to 50%) of shrub cover (Eldridge & Soliveres, 2015).

Argentine rangelands are affected by shrub encroachment processes (Cabral et al., 2003; Peláez et al., 2010). Patagones district has the largest native "Monte," in the southwest of Buenos Aires Province (Giorgetti et al., 2006). In this region, agro-ecological conditions allow the development of livestock activity where it is common to observe overgrazing and high stocking rates (Fernández et al., 2007). The annual distribution of precipitation with high values during autumn and summer allows the deep recharge of the soil in normal years, favoring shrubs development (Kröpfl et al., 2007). However, the ecological system and natural grassland species still persist in Patagones (Peláez, 2011; Torres et al., 2018). Plant diversity preservation (herbaceous and woody species) has been demonstrated to be a valuable tool against desertification in arid and semiarid zones (Maestre et al., 2012) because the ecosystem functions are maximized by the presence of plant species of different functional groups (Maestre et al., 2012, 2016). Species diversity in Patagonian ecosystems allows for mitigating adverse climatic effects; particularly shrubs can contribute to alleviating drought effects on the functioning of rangelands (Gaitán et al., 2014). Moreover, shrubs have a positive influence on plant diversity due to the presence of plant-facilitatory mechanisms (Soliveres et al., 2014) that help to maintain the structural stability of the soil, protect the grasses from the adverse effects of grazing (Eldridge et al., 2015), recycle and store nutrients in the soil of semi-arid environments (Maestre et al., 2009, 2016). Therefore, it becomes necessary to study the real influence that shrub vegetation has on soil quality in rangelands used for livestock purposes.

We hypothesize that shrub sites improve soil quality because the presence of plant species of different functional groups favors microbial activity and increases nutrient availability. The main aims of this study were (I) to evaluate the shrub cover effect on chemical and biochemical parameters of soil quality and (II) to establish relationships among soil quality parameters across vegetation sites of different functional groups in a semiarid Monte rangeland.

2 | MATERIALS AND METHODS

2.1 | Study site

The study was conducted in Chacra Experimental Patagones, a farm located in southwestern Buenos Aires, Argentina (40°39′S, 62°54′W; 40 m.a.s.l.) in spring 2017 and 2018. This area is within the Monte Phytogegraphical Province (Giorgetti et al., 2006). The climate is temperate-semiarid, with precipitations concentrated in summer and autumn. Mean annual precipitation is 430 mm (1981–2019) with a maximum of 877 mm in 1984 and a minimum of 196 mm in 2009 (unpublished data). In 2017 and 2018, mean annual temperatures were 15.2 and 14.9°C, and total annual precipitations were 439 and 489.5 mm, respectively. Monthly precipitation data during the study years are shown in Figure S1.

The soil is classified as a Typic Haplocalcid (Soil Survey Staff, 2014) with texture ranging from loamy and loam-sandy to loam-clay-sandy (Peláez et al., 2010); soil bulk density ranging from 1.08 to 1.43 g cm^{-3}; mean soil moisture and pH are about 5.5% and 7.3, respectively.

The plant community is characterized by an open shrubby stratum, which includes herbaceous species of different qualities for livestock production (Giorgetti et al., 1997; Peláez et al., 2010). The dominant native shrub and perennial grass species are shown in Table 1.

2.2 | Experimental design and sampling

The research was conducted in six paddocks of 10 ha each, on a Monte rangeland (Figure 1). This area has an average shrub and grass

TABLE 1 Dominant shrubs and perennial grass species in the study site.

	Native perennial grasses	
Native shrubs	Preferred	Non preferred
Condalia microphylla Cav	*Nassella longiglumis* (Phil.) Barkworth	*Sporobolus rigens* (Trin.) E. Desv.
Chuquiraga erinacea D. Don	*Nassella tenuis* (Phil.) Barkworth	*Amelichloa ambigua* (Speg.) Arriaga & Barkworth
Larrea divaricata Cav	*Poa ligularis* Nees ex Steud	*Amelichloa brachychaeta* (Godr.) Arriaga & Barkworth
Schinus fasciculata (Griseb.) I.M. Johnst	*Piptochaetium napostaense* (Speg.) Hack.	*Nassella trichotoma* (Nees) Hack. ex Arechav.
Geoffroea decorticans (Gillies ex Hook. & Arn.) Burkart	*Pappophorum vaginatum* Buckley	
Brachyclados lycioides D. Don	*Sporobolus cryptandrus* (Torr.) A. Gray	
Lycium chilense Miers ex Bertero	*Jarava plumosa* (Spreng.) S.W.L. Jacobs & J. Everett	
Neltuma alpataco (Phil.) C.E. Hughes & G.P. Lewis		
Prosopidastrum angusticarpum R.A. Palacios & Hoc		

Note: Perennial grass species were classified according to their forage quality (Giorgetti et al., 1997; Peláez et al., 2010). All species scientific names have been updated according to http://www2.darwin.edu.ar/.

cover of 36% and 19%, respectively, and is exposed to conservative rotational grazing (Peláez et al., 2010). The prolonged drought from 2007 to 2009 did not affect shrub density in these paddocks, showing an increase in shrub cover in the last 10 years (unpublished data).

In each paddock, 10 m transects were randomly placed in a patch with shrubs (Sh) (shrubs cover ≥50% of total plant cover, visually estimated) or without shrubs (WSh) (Figure 1). The length and number of transects were determined considering the patches size and that plant species in the patches were similar between the different paddocks. Within the WSh transect, two soil sampling sites were defined: herbaceous-grass (WSh-G) and bare ground-litter (WSh-BL) cover (Figure 1). In Sh transects, the same sites were defined and called Sh-G and Sh-BL, respectively. In addition, a site under shrub cover (Sh-S) was established in these transects (Figure 1).

In November 2017, a composite soil sample (5 cores per site, 2.5 cm in diameter) was taken at each replicate site ($n = 6$; Figure 1), from 0 to 10 cm deep considering that the highest amount of organic fractions and microbial activity are concentrated in the most superficial layers of the soil (Akinyemi et al., 2020; Carrera et al., 2003; Herman et al., 1995). The samples were transported to the laboratory on ice, and subsequently, each one was separated into subsamples, some of them were refrigerated or air-dried and sieved by 2 mm according to the parameter considered. The study was repeated in 2018 using procedures similar to those of 2017 (same experimental design and sampling; Figure 1), but a new set of transects was defined.

In the experimental design, each paddock was considered as a block divided into 2 years (2017 and 2018) and the sites (soil sampling sites) were included in the experimental design as a subfactor (WSh-G, WSh-BL, Sh-G, Sh-BL, and Sh-S).

2.3 | Soil chemical analyses

Soil samples were analyzed to determine the following parameters: SOM by ignition weight loss method (Martínez et al., 2018); soil organic nitrogen (SON) by micro-Kjeldahl method (Bremner, 1996); inorganic nitrogen (N_i) (NO_3^-–N plus NH_4^+–N) by steam distillation (Mulvaney, 1996), and extractable phosphorus (Pe) by Bray Kurtz I method (Bray & Kurtz, 1945).

The physical fractionation of SOM was performed by wet sieving (Galantini, 2005). The fine fraction (<53 μm) was discarded, particulate organic matter (POM) and particulate organic N (POM-N) were obtained from medium and coarse particle size fraction (53–2000 μm) using the same methods as for SOM and SON, respectively.

2.4 | Soil biochemical analyses

Basal soil respiration (BSR), as an indicator of the metabolic activity of microorganisms, was determined according to the method of Isermeyer (Alef & Nannipieri, 1995) by incubation of soil in a closed system with a NaOH trap for CO_2. Cellulase activity (CA) was estimated by determining the activity of endoglucanases and β-glucosidases after incubating the samples with carboxymethylcellulose (Schinner & Von Mersi, 1990). Colony forming units (CFU) of non-symbiotic N_2-fixing bacteria and phosphate solubilizing microorganisms were quantified in nitrogen-free broth (NFB) and culture medium with $Ca_3(PO_4)_2$ as an insoluble source of P (NBRIP), respectively (Herman et al., 1995). Anaerobic nitrogen (Nan) was determined following the method by Martínez et al. (2017) in a short-term anaerobic incubation. Soil phosphate solubilizing capacity (PSC) was determined by incubating 1 g of soil per sample in Jensen tubes with NBRIP liquid medium for 15 days at 28°C and constant shaking (Das & Debnath, 2006). After that time, soluble P was determined by colorimetric technique (Fiske & Subbarow, 1925).

2.5 | Statistical analysis

Variables were individually analyzed using analysis of variance (ANOVA) with a split block experimental design [main factor: year

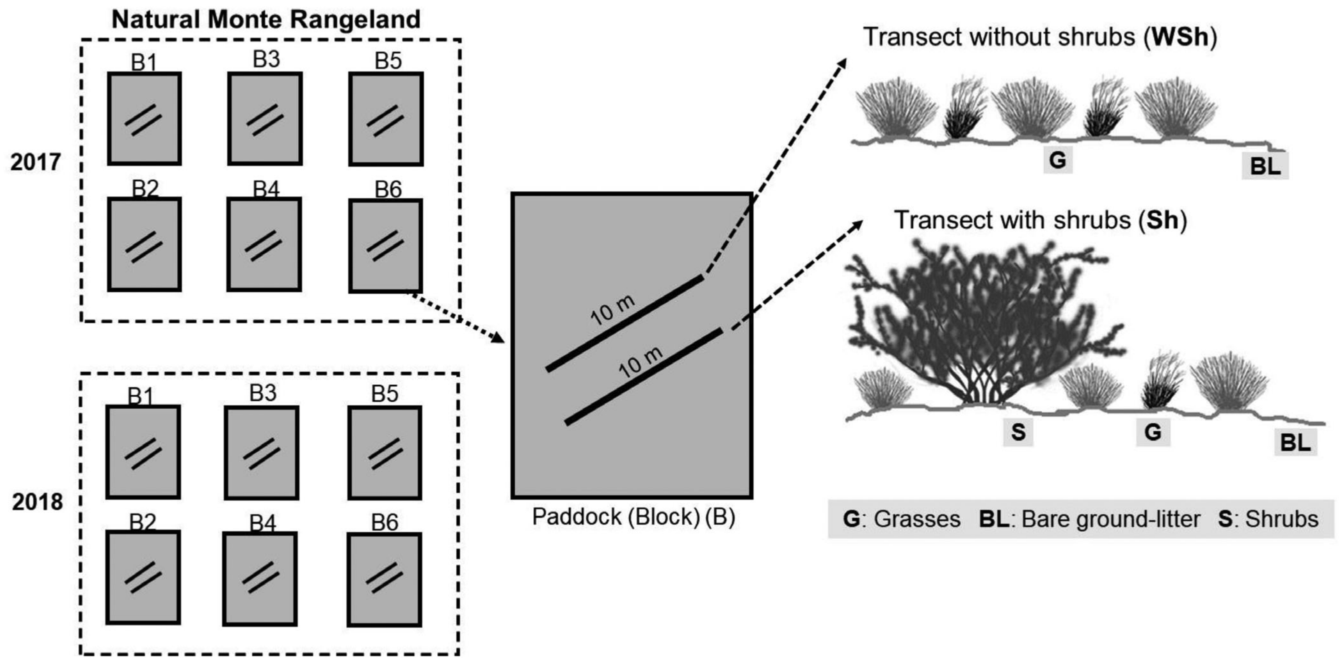

FIGURE 1 Experimental design used for soil sampling (0–10 cm depth) on a Monte rangeland, Chacra Experimental Patagones, Buenos Aires, Argentina.

(2017 and 2018); subfactor: site (Sh-G, Sh-BL, Sh-S, WSh-G, and WSh-BL)] to evaluate shrub cover effect on chemical and biochemical parameters of soil quality. In the variables (i.e., SOM, Pe, CA, and CFU NBRIP) that the ANOVA detected a significant interaction ($p \le 0.05$) between the factors year and site, we proceeded to separate the analysis by year, to compare the means among sites, and to separate by the site to compare the means between years. The variables SOM, Pe, CA, and CFU in the NFB medium were transformed to ln (x) and POM, BSR, and CFU in the NBRIP medium were transformed to $\sqrt{x}$ to comply with the ANOVA assumptions of normality and homoscedasticity (Sokal & Rohlf, 1984). A comparison of means was conducted using the protected Fisher test (LSD), with a significance level of 0.05. All reported data correspond to untransformed values.

A principal component analysis (PCA) was performed to establish relationships among soil quality parameters across soil sampling sites. Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy (KMO > 0.50) and Bartlett's test of sphericity ($p < 0.05$) were conducted to evaluate the suitability of individual and set variables for PCA. The selection of the main components was determined by the latent root criterion (eigenvalues >1.0).

All statistical analyses were conducted with Infostat and XLSTAT software (Addinsoft, 2022; Di Rienzo et al., 2018).

3 | RESULTS

3.1 | Chemical parameters of soil quality

Soil sampling sites presented similar SOM contents in 2017. However, in 2018, Sh-S sites presented higher values of this parameter than Wsh-G and bare ground-litter soils in both, shrub and without shrubs transects (Figure 2a).

Grass and shrub soils of shrub transects showed the highest POM and in all studied sites values were higher in 2018 than in 2017 (Figure 2b). Shrub soils presented higher mean values of SON than bare ground-litter soils of transects with and without shrubs (Figure 2c). All sampling sites showed similar values for the rest soil quality parameters related to the N cycle (Figure 2d,e).

Mean values of Pe varied between different sites and study years. In 2017 within shrub transects, Sh-S sites showed higher Pe than bare ground-litter and grass soils (Figure 2f). However, in 2018, Sh-S sites presented the highest values for this parameter and grass soils presented higher Pe in shrub than without shrub transects (Figure 2f).

3.2 | Biochemical parameters of soil quality

Sampling sites showed similar soil microorganisms' overall activity estimated from BSR (Figure 3a). Values of CA varied between different sites and study years. In 2017 within each transect, activity values were higher in sites with vegetation cover than in bare ground-litter soils (Figure 3b). However, in 2018, all sites within shrub transects presented higher CA than those in transects without shrubs (Figure 3b).

Regarding counts performed on selective media, there were no significant differences between sites in CFU of non-symbiotic N_2-fixing bacteria growing in NFB (Figure 3c). Only in 2017, CFU of phosphate solubilizing microorganisms growing in NBRIP of bare ground-litter soils were higher in shrub than without shrub transects, whereas for grass soils there was no significant effect of shrub cover (Figure 3d).

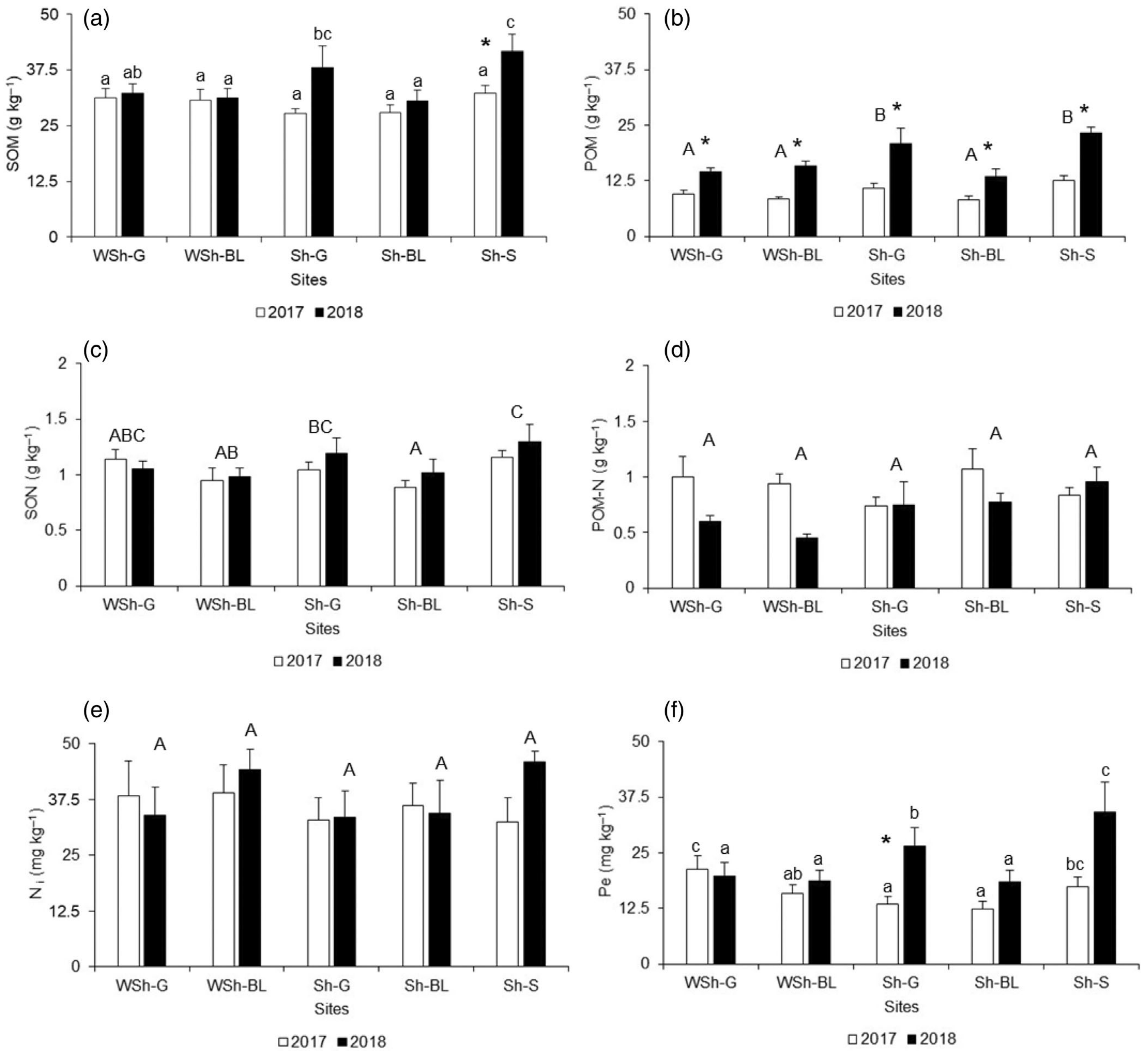

FIGURE 2 Mean soil chemical parameters of soil quality in different sites with shrubs (Sh) or without shrubs (WSh) and soil cover: Bare ground-litter (BL), Grass (G), and Shrub (S). Each histogram is the mean ± 1 SE. Different lowercase letters (a and f) indicate significant differences ($n = 6$; Fisher's LSD, $p \le 0.05$) between sites for 2017 and 2018. Different uppercase letters (b, c, d, and e) indicate significant differences ($n = 12$; Fisher's LSD, $p \le 0.05$) between sites in both years. *Indicate significant differences (Fisher's LSD, $p \le 0.05$) between years within each site. N_i, inorganic nitrogen; Pe, extractable phosphorous; POM, particulate organic matter; POM-N, particulate organic nitrogen; SOM, soil organic matter; SON, soil organic nitrogen.

In both years, all studied sites presented similar Nan and PSC values (Figure 3e,f).

3.3 | Relationships among soil quality parameters

In 2017, the parameters CFU NBRIP, CFU NFB, and PSC were not included in the PCA, because they presented individual adequacy values less than 0.5. For the set of variables, KMO measure of sampling adequacy was 0.687 and Bartlett's test of sphericity was highly significant ($p < 0.0001$, Table 2). The first three PCA's components showed a 75% contribution rate and contained almost all the analyzed information (Table 3). The first principal component's eigenvalue was 3.89 and displayed a positive correlation with SOM, POM, SON, Pe, BSR, CA, and Nan ($r \ge 0.6$; Tables 3 and 4). The second principal component's eigenvalue was 1.87 and displayed a positive correlation with SOM, POM-N, and N_i ($r > 0.4$) and negative with CA ($r < -0.4$; Tables 3 and 4). The third principal component's eigenvalue

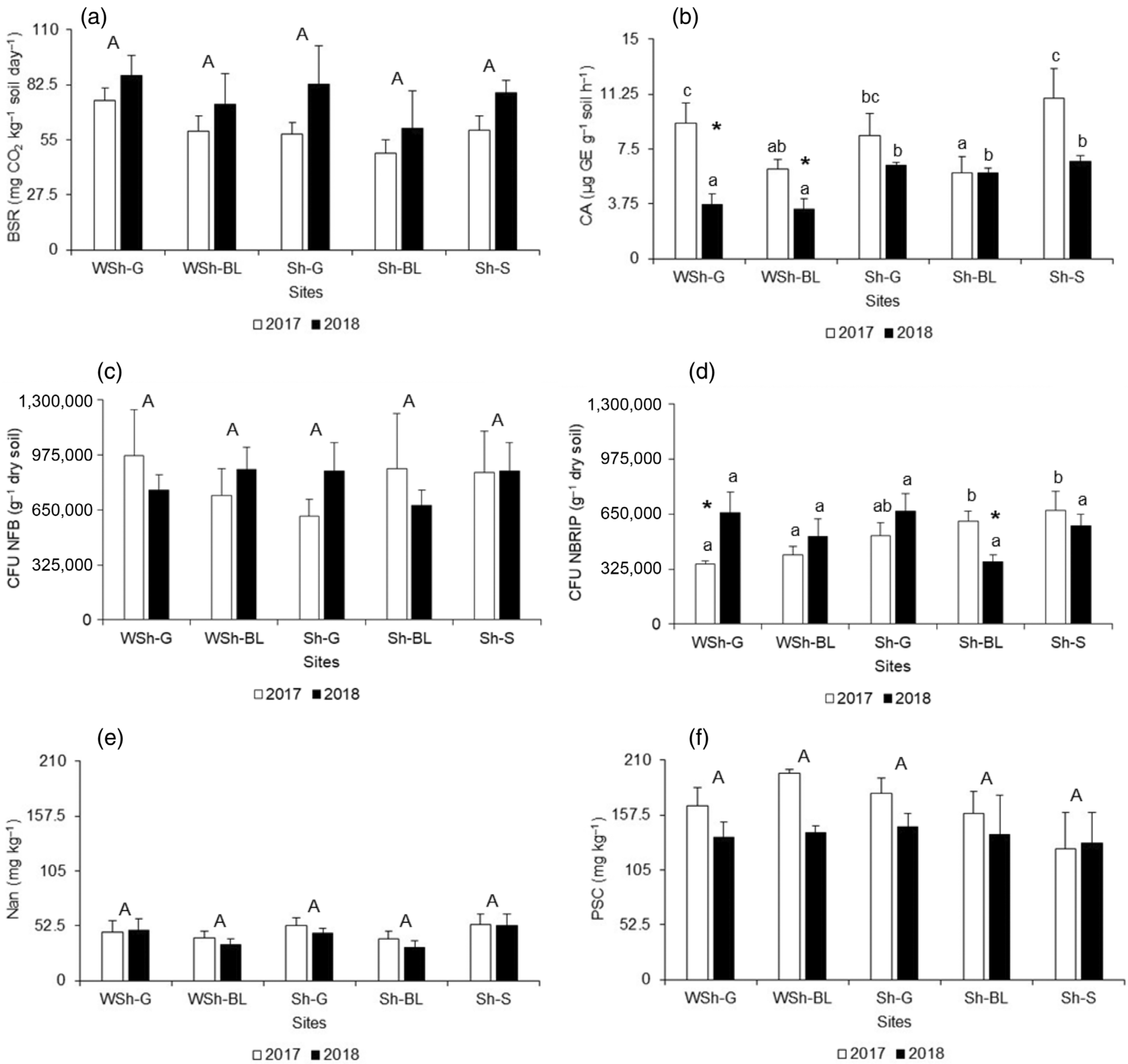

FIGURE 3 Mean soil biochemical parameters of soil quality in different sites with shrubs (Sh) or without shrubs (WSh) and soil cover: bare ground-litter (BL), grass (G), and shrub (S). Each histogram is the mean ± 1 SE. Different uppercase letters (a, c, e, and f) indicate significant differences ($n = 12$; Fisher's LSD, $p \le 0.05$) between sites in both years. Different lowercase letters (b and d) indicate significant differences ($n = 6$; Fisher's LSD, $p \le 0.05$) between sites for 2017 and 2018. * Indicate significant differences (Fisher's LSD, $p \le 0.05$) between years within each site. BSR, basal soil respiration; CA, cellulase activity; CFU NBRIP, colony forming units in NBRIP; CFU NFB, colony forming units in NFB; Nan, anaerobic nitrogen; PSC, phosphate solubilizing capacity.

was 0.97 and displayed a positive correlation with BSR ($r > 0.6$; Tables 3 and 4). The first two components recovered more than 55% of the total variance of SOM, POM, SON, POM-N, N_i, CA, and Nan. Sh-S sites were associated with higher values of SOM, SON, Nan, CA, and POM compared to bare ground-litter soils of transects with and without shrubs (Figure 4a); grass soils presented intermediate values to those of the other sites in both transects, whereas variables N_i and POM-N were not associated with any soil sampling site (Figure 4a). The first and third components obtained an 86% reconstruction of BSR that did not show a relationship with any site.

In 2018, the parameter CFU NFB was not considered in the PCA, because it presented individual adequacy values less than 0.5. For the set of variables, KMO measure of sampling adequacy was 0.716 and Bartlett's test of sphericity was highly significant ($p < 0.0001$, Table 2). The contribution rate of the first three PCA's components was 67%, and also contained almost all the analyzed information (Table 3). The first principal component's eigenvalue was 4.44 displayed a positive correlation with SOM, POM, N_i, SON, POM-N, CA, and BSR ($r > 0.5$) and negative with PSC ($r < -0.5$) (Tables 3 and 4). The second principal component's eigenvalue was 1.65 and displayed a positive correlation with Pe, CA, and PSC ($r \geq 0.5$) and negative with BSR ($r < -0.6$) (Tables 3 and 4). The third principal component's eigenvalue was 1.24 and displayed a positive correlation with CFU NBRIP and Nan ($r > 0.4$) and negative with N_i ($r < -0.4$) (Tables 3 and 4). The first two components explained more than 55% of the total variance of SOM, POM, SON, POM-N, BSR, CA, and PSC. Sh-S sites were associated with higher values of SOM, POM, N_i, SON, POM-N, CA, and BSR and lower values of PSC compared to WSh-BL sites, whereas grass soils of shrub transects presented intermediate values to those of the other sites (Figure 4b). The first and third components obtained more than 50% reconstruction of N_i and Nan that did not show a relationship with any site.

TABLE 2 Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity for principal component analysis in each study year (2017 and 2018).

2017		
KMO		0.687
Bartlett's test of sphericity	χ^2	127.923
	df	36
	p-value	<0.0001
2018		
KMO		0.716
Bartlett's test of sphericity	χ^2	139.065
	df	55
	p-value	<0.0001

4 | DISCUSSION

This study is the first to perform a holistic approach to shrub effects on several chemical and biochemical parameters of soil quality in the semiarid rangelands of northwestern Patagonia. Although we did not detect an improvement in all variables, as expected in the hypothesis, the results show that in the context of conservative rotational grazing, shrub presence has a positive effect on different indicators of soil quality, mainly with those related to C cycle and organic matter decomposition (i.e., SOM, POM, SON, and CA).

TABLE 3 Results of principal component analysis (PCA) performed in 2017 and 2018. Eigenvalues, proportion, and cumulative variance are explained by the first three PCA's components.

	2017			2018		
	Component			Component		
	1	2	3	1	2	3
Eigenvalue	3.89	1.87	0.97	4.44	1.65	1.24
Proportion of variance	0.43	0.21	0.11	0.4	0.15	0.11
Cumulative variance	0.43	0.64	0.75	0.4	0.55	0.67

TABLE 4 Results of principal component analysis (PCA) performed in 2017 and 2018. Correlations between the considered soil quality parameters and PCA's components.

	2017			2018		
	Component			Component		
Soil quality parameter	1	2	3	1	2	3
SOM	0.73	0.51	−0.18	0.93	0.06	0.08
POM	0.8	−0.35	−0.29	0.81	0.15	−0.23
SON	0.8	0.15	−0.26	0.9	0.01	0.13
POM-N	0.27	0.82	−0.13	0.77	0.15	−0.22
N_i	0.11	0.74	0.31	0.53	−0.37	−0.48
Pe	0.6	−0.04	−0.36	0.1	0.65	−0.33
BSR	0.64	0.07	0.67	0.53	−0.62	−0.0038
CA	0.79	−0.41	0.25	0.57	0.57	−0.12
Nan	0.78	−0.27	0.21	0.47	0.09	0.72
CFU NBRIP				0.29	0.27	0.49
PSC				−0.57	0.5	−0.07

Note: Soil quality parameters: soil organic matter (SOM); particulate organic matter (POM); soil organic nitrogen (SON); particulate organic nitrogen (POM-N); inorganic nitrogen (N_i); available phosphorous (Pe); basal soil respiration (BSR); cellulase activity (CA); anaerobic nitrogen (Nan); colony forming units in NBRIP (CFU NBRIP); and phosphate solubilizing capacity (PSC).

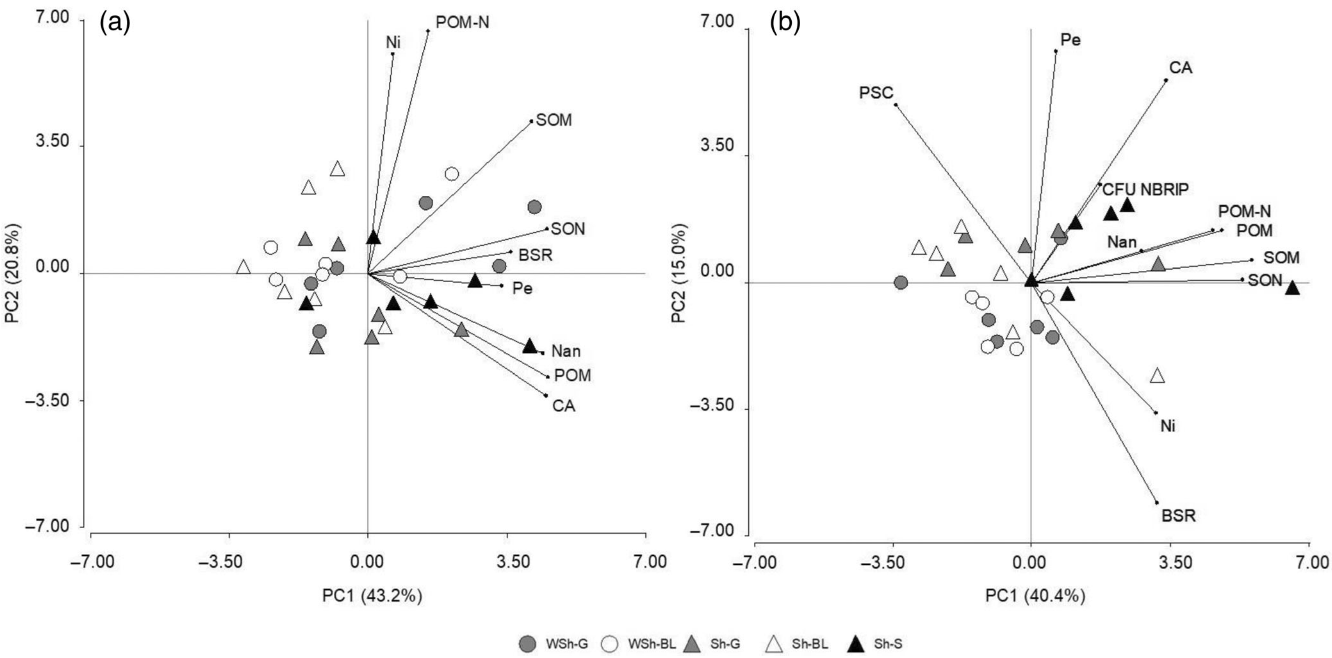

FIGURE 4 Bi-plot graphic of principal component analysis (PCA) performed in 2017 (a) and 2018 (b) on chemical and biochemical parameters of soil quality and its relation with different sites with shrubs (Sh) or without shrubs (WSh) and soil cover: bare ground-litter (BL), grass (G) and shrub (S). Parameters analyzed: soil organic matter (SOM); particulate organic matter (POM); soil organic nitrogen (SON); particulate organic nitrogen (POM-N); inorganic nitrogen (Ni); extractable phosphorous (Pe); basal soil respiration (BSR); cellulase activity (CA); colony forming units in NBRIP (CFU NBRIP); anaerobic nitrogen (Nan); and phosphate solubilizing capacity (PSC). Percent of variability explained by each principal component (PC) is shown in parentheses on each axis. Cophenetic correlation: 0.923 (a) and 0.912 (b).

4.1 | Shrub cover effect on chemical parameters of soil quality

The SOM values were different between years and sampling sites. Only in 2018, high organic matter contents were detected in Sh-G and Sh-S sites (Figure 2a). Precipitations during 2018 were higher than in 2017 (489.5 and 439 mm, respectively), and spring rains doubled those registered during the same period with regard to the first study year (Figure S1). Higher precipitation has been associated with increases in shrubs species litter production and in germination and establishment of annual species (Campanella & Bertiller, 2010; Torres et al., 2021); these events increase organic matter contributions to the soil favoring decomposition processes (Ambrosino et al., 2019).

Particulate organic matter represents the youngest and most active organic material in the soil and its decomposition is heavily dependent on residue input and weather conditions (Martínez et al., 2017). Campanella and Bertiller (2010) studied leaf litterfall patterns of perennial plant species (shrubs and grasses) in arid Patagonia and demonstrated that in most shrub species, and *Poa ligularis* (present in the soil sampling sites) increased precipitation was related to increased litter production. Moreover, *Chuquiraga erinacea*, one of the shrubs species with the greatest coverage and abundance in the studied transects (19.8% and 0.6 plants m^{-2}; unpublished data), has the main peak of leaf litter production in winter-early spring (Campanella & Bertiller, 2010). These findings contribute to explain the interannual differences registered in our study and higher POM values in Sh-G and Sh-S sites in both years (Figure 2b). High fresh organic matter content in the Sh-G sites represents an increase in the reserve of nutrients potentially available to mineralize and demonstrates the beneficial effect of shrubs on soil quality proposed in the study hypothesis.

The quantity and quality of litter exert an important control on the N dynamics in semi-arid environments (Ambrosino et al., 2019, 2021). Studies carried out in the Phytogeographic Province of Monte have shown diverse results in relation to soil N dynamics. Mazzarino et al. (1996) found higher N_i contents in grass-shrub patches than in grass patches and those without vegetation. Carrera et al. (2003) found higher SON contents under evergreen shrubs than perennial grasses; however, these differences were lower than expected considering the litter quality provided by each plant functional group. In our study, Sh-S sites presented higher values of SON than BL soils in both WSh-BL and Sh-BL sites (Figure 2c). A low N reabsorption from green leaves of shrubs leads to litter production with higher N contents that increase the SON values (Mazzarino et al., 1996). Although we observed a slight tendency towards higher POM-N and N_i contents in shrub transects these differences were not significant when both parameters were studied separately (Figure 2d,e). Studies that analyzed the composition of green and senescent leaves of the same shrub species present in our studied transects found a high concentration of phenolic compounds in evergreen shrubs of the genus *Larrea* and high concentrations of lignin in evergreen shrubs of the genus

Chuquiraga and deciduous shrub *Neltuma alpataco* (Campanella & Bertiller, 2011). Secondary compounds in the litter may delay N release to the soil and N cycling (Carrera et al., 2009). Moreover, livestock directly and indirectly affect soil nitrogen dynamics (Sirotnak & Huntly, 2000). In the sampling sites, soil disturbance, trampling, and incorporation of feces and urine together with selective herbivory by cattle might homogenize soil properties and decrease the effect of species functional groups on N availability.

Extractable phosphorus values varied between sites and study years and it was difficult to establish a clear distribution pattern. Within the Sh transects, Sh-S sites presented the highest Pe values in both years; while in 2018, grass soils presented higher Pe in shrub than without shrub transects (Figure 2f). Several studies show that shrubs can alter soil physicochemical characteristics through their radical exudates (López et al., 2003), increasing phosphatase activity responsible for P organic mineralization to soluble forms available for plants (Akinyemi et al., 2020; Maestre et al., 2011). These findings could be responsible for the higher Pe values found in shrub sites in our study (Figure 2f).

4.2 | Shrub cover effect on biochemical parameters of soil quality

No effect of shrub presence was detected on BSR when this parameter was analyzed individually (Figure 3a). These results are opposite to those expected in the hypothesis and those reported in other studies where higher values of soil respiration were detected beneath shrub plants than in sites without them (Chandregowda et al., 2018). However, results obtained using more sensitive parameters, such as CA, showed higher activity in vegetation patches than in bare ground-litter soils (Figure 3b). Moreover, in 2018 a clear effect of shrub presence was detected since all soil samples of sites in shrub transects presented higher activity than those obtained in without shrubs ones (Figure 3b). These results could be related to high contents of SOM, POM, and SON in both Sh-G and Sh-S sites (Figure 2a–c); high residue input and soil organic carbon favor the microbial activity of inducible enzymes and organic matter decomposition processes (Akinyemi et al., 2020; Maestre et al., 2009, 2011).

In general, CFU of non-symbiotic N_2-fixing and phosphate-solubilizing bacteria were not affected by the presence of shrubs; the same occurred with the PSC of the soil (Figure 3c,d,f). It is possible that the availability of N and P may not have been a determining factor in promoting the development of these microorganisms or affecting phosphate solubilization capacities in any of the soils tested.

Anaerobic nitrogen is considered a soil quality indicator and various studies report higher values of potential mineralization of N in shrub sites, mainly due to better microclimatic conditions below their canopy and availability of labile substrates (Carrera et al., 2003; Chandregowda et al., 2018; Eldridge et al., 2011). In our study, when Nan was studied individually, no significant differences were observed between years and soil samples (Figure 3e). These results could be due to the fact that most of the labile N fractions available for mineralization were similar among the different study sites.

4.3 | Relationships among soil quality parameters across vegetation sites of different functional groups

Chemical and biochemical parameters followed different association patterns according to the year considered; however, values of SOM, POM, SON, and CA were positively correlated and associated with Sh-S in both years and Sh-G sites in 2018 (Table 4 and Figure 4). These results are in agreement with the study hypothesis and demonstrate an improvement in soil quality due to the presence of plant species of different functional groups compared to areas dominated by grass species. Thirty-two percent of the woody species in Sh transects are deciduous, with representatives of the Fabaceae family (Torres et al., 2021). These shrubs' species favor the absorption of nitrogen by grasses growing beneath them, herbaceous biomass production, and atmospheric N fixation (Gargaglione et al., 2014). The higher litter contribution increases microbial biomass (Yannarell et al., 2014) and through root exudates shrubs can stimulate heterotrophic soil microorganisms (Wallenstein et al., 2007) and mineralization of organic matter (Gargaglione et al., 2014), enhancing CA necessary for fresh litter decomposition.

Bare ground-litter sites among vegetation patches are the result of topographic characteristics and previous grazing mismanagement (Ambrosino et al., 2018). Contrary to what happened in Sh-G and WSh-G sites, BL soils of the WSh-BL and Sh-BL sites were associated with the lowest values of SOM, POM, SON, and CA in both years (Figure 4). These results show that in this semiarid environment shrub cover would have a higher impact on the soil quality of the herbaceous stratum than on bare interspaces. Moreover, in 2018, Sh-G sites were associated with higher values of SOM, POM, SON, and CA compared to WSh-G sites (Figure 4b), demonstrating that shrub presence should not be generalized as an indicator of ecological degradation of semiarid environments since soils were linked to increased values of most chemical and biochemical parameters studied.

5 | CONCLUSIONS

The results of this study showed that the presence of shrub species in the Monte rangeland should not be directly linked to the formation of fertility islands under them affecting adjacent open spaces and favoring soil quality loss. Although we did not detect a shrub effect in all parameters studied, in the context of appropriate grazing management, the presence of plant species of different functional groups has a positive effect on organic matter and N content of soil close to them. Moreover, in these sites, high POM values represent an important reservoir of potentially available nutrients and promote CA necessary for fresh litter decomposition improving the soil quality of semiarid rangelands.

Shrub encroachment is a complex and multifaceted phenomenon, long-term studies are needed to monitor soil quality in patches with different functional groups of plant species. However, synergistic interactions between different plant species and the positive effect of shrubs on soil should be considered in the implementation of sustainable management practices aimed to improve forage resources and reduce desertification processes in semiarid environments.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Research data are not shared.

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