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ARTICLE

Rehabilitation of Semi-Arid Grasslands through the Perennialization of Lots by Implementing Perennial Forage Exotic Grass

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ABSTRACT

Argentina is the country with the highest proportion of arid and semi-arid ecosystems in Latin America. In the rangelands of Southwestern Buenos Aires (Patagones Department), there is a clear advancement of the agricultural frontier to the detriment of the native forest in this region. Due to rainfall variation and seed acquisition, *Thinopyrum ponticum* is cultivated as a forage perennial crop in this region. Our objective was to evaluate the performance of *T. ponticum* as a facilitating crop for the medium-term rehabilitation of natural grasslands in semi-arid areas. The working hypotheses were that: 1) native perennial grass cover increases over the years and 2) diversity and specific richness of the vegetation are enhanced by the duration of Tall Wheatgrass implantation. Data were collected from commercial plots where *T. ponticum* was shown: recent implantation (5–8 years, RI); medium implantation (13–15 years, MI); and old implantation (20–22 years, OI). Thirty-four species were identified and classified into seven functional groups: Annual grasses, annual herbs, perennial herbs, exotic perennial herbs, perennial forage grasses, exotic perennial forage grasses, perennial forage exotic grasses, and non-forage perennial grasses. *Thinopyrum ponticum*'s total cover was between RI and OI. Total cover, species richness, and Shannon-Weaver diversity index showed no differences among treatments. Perennial forage grasses exhibited higher cover values in sites with greater implantation age and annual grasses showed the opposite response. Our results indicated that *T. ponticum* does not invade the sampled plots and enhances the colonization of the planted plots by perennial forage native species. However, even though the herbaceous cover had been recovered, the woody layer which could provide environmental services and specific values for conservation was not.

KEYWORDS

Wheatgrass; clearing vegetation; monte; *Thinopyrum ponticum*

1 Introduction

Arid and semi-arid zones are essential for human development in many parts of the world and they sustain approximately 50% of global livestock [1]. These areas exhibit a relationship between medium annual precipitation and medium potential evapotranspiration of less than 0.65 [2]. More than 65% of these ecosystems are used for grazing, with natural vegetation serving as forage for domestic livestock, whereas only 25% are dedicated to agriculture [1].

These ecosystems are complex and multifunctional, often resulting in the provision of a wide range of services overlooked during management planning. They are highly sensitive to the impact generated by anthropogenic activities, which brings about a loss of resilience [3]. Consequently, they have become degraded due to actions such as the introduction of agricultural or forage crops, often followed by the total or partial removal of native vegetation (woody and herbaceous), without consideration for soil and climatic characteristics that influence their stability and sustainability [4].

Argentina contains arid, semi-arid, and dry sub-humid areas, being the Latin American country with the highest proportion (75%) of these ecosystems [5]. Here, the primary use of semi-arid ecosystems is oriented towards livestock grazing [6]. The incorporation of large land areas in the transition zone between Monte and Espinal into new productive paradigms was possible through the deforestation of native vegetation. These changes in the use of the land have enhanced degradation, which causes an impact on the environmental, social, and economic aspects [7].

The rangelands of Southwestern Buenos Aires (Patagones Department) are part of the semi-arid regions of Argentina. The phytogeographical analysis proposed by Oyarzabal et al. [8] classifies this region into the vegetation unit known as Monte Oriental, which belongs to the phytogeographical province of Monte. The tree stratum is primarily represented by *Geoffroea decorticans*, while the shrub stratum includes *Condalia microphylla*, *Neltuma flexuosa* var. *depressa*, *Larrea divaricata*, and *Chuquiraga erinacea*, among others. Regarding the herbaceous stratum, it is dominated by the *genera Jarava*, *Nassella*, and *Poa*, although other species of high forage value such as *Pappophorum caespitosum*, *Medicago minima*, and *Erodium cicutarium* are also present [9].

Within the Patagones Department, the primary economic activity is oriented to livestock grazing [6]. However, there is a clear advancement of the agricultural frontier at the expense of the native forest in this region [10]. In 1975, dryland and irrigated agricultural lands accounted for 31% of the total surface area of the Department. This shift in land use resulted in a reduction of the area covered by native vegetation, which currently accounts for 20% [10].

In this semi-arid zone, agriculture productivity is highly dependent on precipitation, as the system is favored only if sowing coincides with a wet period [11].

In the area of study, the agricultural frontier advance includes woody plant cover management (reduction or total removal). Kröpfl et al. [12,13] observed that mechanically cleared sites exhibited symptoms of aridization and concluded that reversion may require active intervention by those managing the system. Rehabilitation and restoration of natural ecosystems consider pre-existing ecosystems as reference points. The difference is that while rehabilitation aims to recover processes, productivity, and ecosystem services, restoration pursues those goals and also seeks the reinstatement of the composition and structure of species from the original community [14].

Ecological restoration and rehabilitation employ native species adapted to the environmental conditions of the area to be restored [15]. Since seeds of native species are not commercially available, and harvesting in natural fields is technically difficult due to the absence of machines adapted to the morphology of the seeds and native plants, a commercially used exotic species was employed in this study. For the same reason, exotic species are cultivated for forage by farmers. One of the most used is Tall Wheatgrass (*Thinopyrum ponticum*), a perennial, tufted, glabrous grass, ranging from 0.70 to 1.40 m in height, whose growth is concentrated in the autumn. It is considered a forage with high nutritional value, high production, and resistance to grazing [16]. It is extremely tolerant to salinity and has only the drawback of some initial slow growth [17]. This species, alone or in association with others, requires a period to establish itself and be able to be used for direct grazing without the risk of losing grass due to damage from herbivores [17]. Patagones Department presents optimal an agro-climatic range for the development of this species because it possesses a precipitation range between 350 and 600 mm, and temperatures between 12°C and 20°C [18]. Its climatic characteristics, low natural reseeding capacity, and foraging pressure collectively limit the potential of *T. ponticum* to become an invasive species [18]. Some farmers in the area, upon observing native species colonization on the wheatgrass, have reseeded this pasture. This practice is carried out every 5 to 7 years to maintain the wheatgrass cultivation.

Taking advantage of the advancement of the native plant community on the implanted pasture, the objective of this work was to evaluate the performance of Tall Wheatgrass as a facilitating crop for medium-term natural grassland rehabilitation in semi-arid areas. The working hypotheses were that: 1) native perennial grass cover increases over the years and 2) diversity and specific richness of the vegetation are enhanced by the duration of Tall Wheatgrass implantation. The significance of this study lies in the complementary use of the facilitating crop until the rehabilitation of the system's functions (e.g., soil protection, forage provision, and improvement of soil infiltration and fertility) through colonization by native forage grasses.

2 Material and Methods

Sampling was conducted in commercial grazing properties located in Patagones Department in Buenos Aires province. The plots evaluated in this study have not been reseeded, and correspond to different implanting dates. The sowing was made in clear plots where it was used direct sowing with a density of 52 plants per square meter [19]. In the region, *T. ponticum* is used to perpetuate plots that have a history of use associated with extensive agriculture [6]. These plots were formerly used for the cultivation of winter or summer annual species (*Avena* spp., *Sorghum* spp.). Due to the inter and intra-annual variation in rainfall, farmers have changed their production practices and have begun to adopt perennial species [19]. According to their age, we have grouped them into three categories. Thus, data were collected from the vegetation of plots where *T. ponticum* was implanted 5, 7, and 8 years ago (A5, A7, A8); 13, 14, and 15 years ago (A13, A14, A15); and 20, 21, and 22 years ago (A20, A21, A22). Fig. 1 shows the geographical location of the sampling points. All plots where samples were taken correspond to plots where *Thinopyrum ponticum* was implanted and no further mechanical interventions were carried out on the soil, with the exception of grazing by sheep and cattle.

The plots A8, A15, and A20 correspond to the same field, Patagones Experimental Ranch. Similarly, plots A5 and A14, as well as A13 and A7, correspond to identical fields. Samples were taken from a single plot in fields A22 and A21.

The point intercept method was used for field sampling [20]. A random site within the plot was selected to conduct the first 20-meter transect oriented North-South. This transect served as a reference to locate the other four transects following the same orientation and spaced 15 m apart. A touch was made every 20 cm along each 20-meter transect, resulting in 100 points per transect and a total of 500 points per plot. For each touch, the species name was recorded, as well as whether it touched bare soil, litter, or dung.

The species present in all sampling sites were classified into the following functional groups: Annual grasses (AG), annual herbs (AH), perennial herbs (PH), exotic perennial herbs (EPH), perennial forage grasses (PFG), exotic perennial forage grasses (EPFG), and non-forage perennial grasses (NFPG).

Following Peri et al. [21], total vegetation cover and cover by functional groups were estimated. Additionally, Shannon-Weaver diversity and species richness indices were calculated.

For data analysis, Infostat program [22] was used. The modified Shapiro-Wilk normality test and homoscedasticity test were performed to assess the normal distribution of the data. As the assumptions of normality and homoscedasticity were not met, the Kruskal-Wallis test was used. Fisher's LSD test was employed to compare means with a significance level of $p < 0.05$.

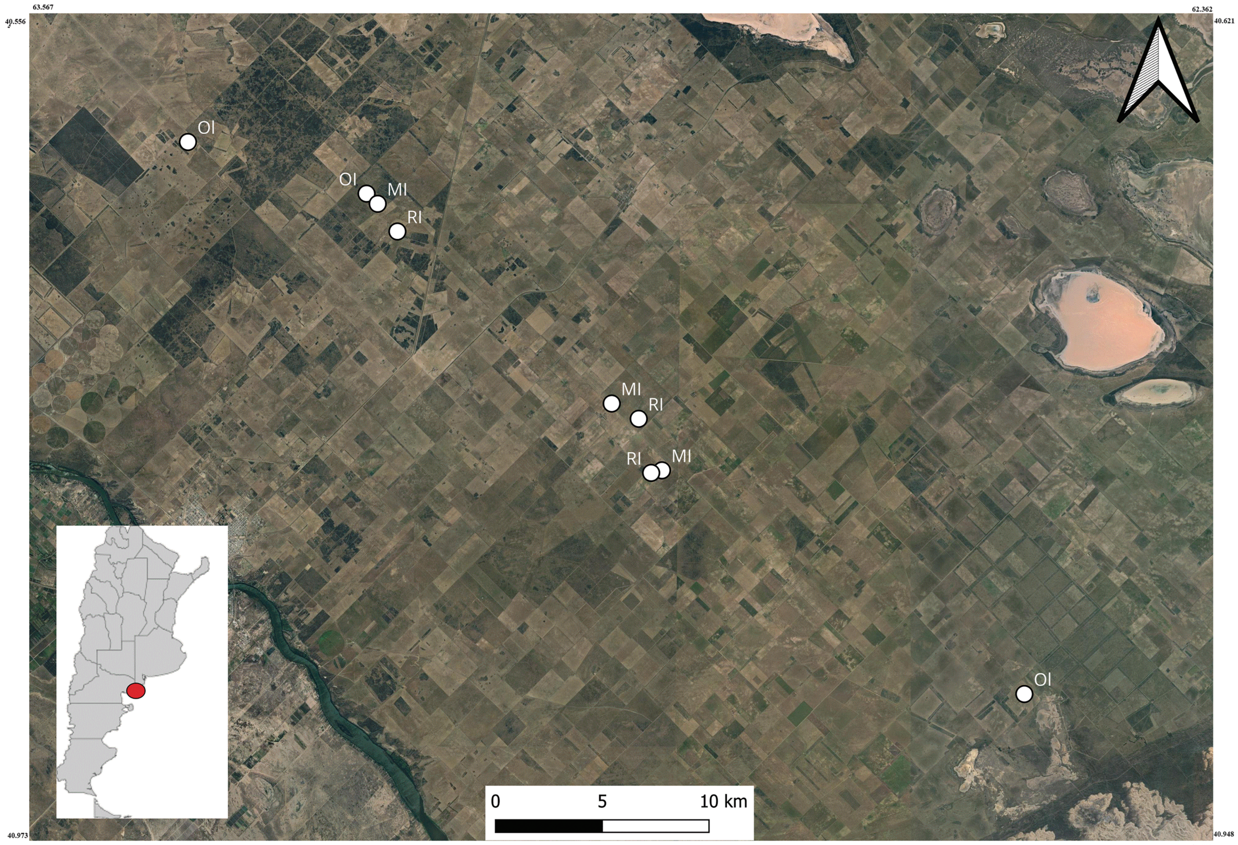

Figure 1: Sampling sites geographic location

3 Results

The cover of *Thynopirum ponticum* was higher in sites where the implantation date was more recent (RI) than in sites of old implantation date (OI) (Fig. 2).

Thirty-four species were identified and classified into the seven functional groups previously mentioned: annual grasses (AG), annual herbs (AH), perennial herbs (PH), exotic perennial herbs (EPH), perennial forage grasses (PFG), exotic perennial forage grasses (EPFG), and non-forage perennial grasses (NFPG) (Table 1).

Total cover of the sampled sites showed no significant differences among treatments (Table 2). Cover of the different functional groups identified in sites of varying ages showed a higher cover of annual grasses (AG) compared to older sites (OI) (Fig. 2). Species classified within this functional group included *Eragrostis mexicana*, *Lolium multiflorum*, *Poa annua*, and *Schismus barbatus*.

Perennial forage grasses (PFG) exhibited higher cover values in sites with greater age implantation with *Thinopyrum ponticum* (MI and OI) (Fig. 3). Species classified within this functional group included *Distichlis scoparia*, *Jarava plumosa*, *Nassella longiglumis*, *Nassella tenuis*, *Pappophorum vaginatum*, *Pappophorum caespitosum*, and *Setaria mendocina*.

The remaining functional groups did not exhibit significant differences across the different implantation times of *Thinopyrum ponticum* (Table 2).

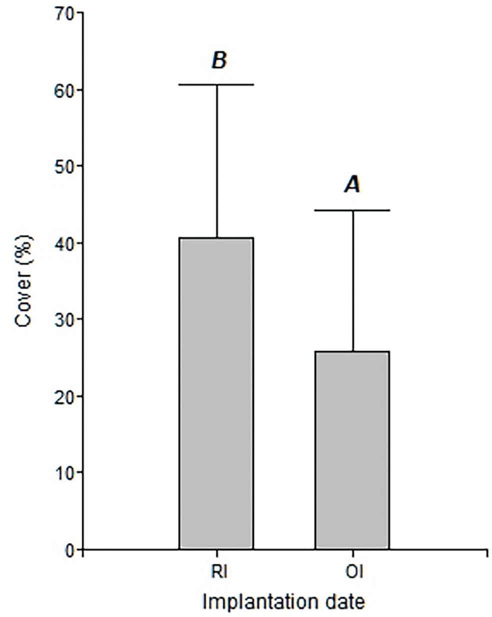

Figure 2: Cover (%) of *Thynopirum ponticum* in sites of recent (RI) and old (OI) implantation date. Different letters indicate statistically significant differences ($p < 0.05$)

Table 1: Functional groups identified in the floristic surveys of plots implanted with *Thinopyrum ponticum*

Species	Forage condition	Status
Annual grasses (AG)		
Eragrostis mexicana	Yes	Native
Lolium multiflorum	Yes	Exotic
Poa annua	Yes	Exotic
Schismus barbatus	Yes	Exotic
Annual herbs (AH)		
Centaurea solstitialis	No	Exotic
Erodium cicutarium	Yes	Exotic
Euphorbia sp.	No	Native
Facelis retusa	No	Native
Medicago minima	Yes	Exotic
Portulaca oleracea	No	Exotic
Salsola kali	Yes	Exotic
Tribulus terrestris	No	Exotic
Perennial herbs (PH)		
Baccharis gilliessi	No	Native
Gaillardia megapotamica	No	Native

(Continued)

Table 1 (continued)

Species	Forage condition	Status
Hoffmannseggia erecta	No	Native
Hoffmannseggia trifoliata	No	Native
Nierembergia linariaefolia	No	Native
Solanum elaeagnifolium	No	Native
Sphaeralcea bonariensis	No	Native
Dichondra microcalyx	No	Native
Exotic perennial herbs (EPH)		
Atriplex semibaccata	Yes	Exotic
Perennial forage grasses (PFG)		
Distichlis scoparia	Yes	Native
Jarava plumosa	Yes	Native
Nassella longiglumis	Yes	Native
Nassella tenuis	Yes	Native
Pappophorum vaginatum	Yes	Native
Pappophorum caespitosum	Yes	Native
Setaria mendocina	Yes	Native
Exotic perennial forage grasses (EPFG)		
Eragrostis curvula	Yes	Exotic
Thinopyrum ponticum	Yes	Exotic
Non-forage perennial grasses (NFPG)		
Amelichloa ambigua	No	Native
Aristida spegazzinii	No	Native
Eragrostis lugens	No	Native
Pappostipa speciosa	No	Native

Table 2: Means (percentage) and standard deviation of soil cover by different functional groups, species richness, and Shannon-Weaver diversity index. Different letters indicate significant differences ($p < 0.05$)

Treatment	RI	MI	OI
	Mean (SD)	Mean (SD)	Mean (SD)
Cover			
Total	83.60 (35.65)	73.53 (25.24)	76.93 (23.60)
AG	**2.73 (3.79) A**	**0.73 (1.49) AB**	**0.20 (0.41) B**
AH	15.27 (34.64)	7.00 (11.15)	8.53 (13.42)
PFG	**9.73 (8.63) A**	**28.60 (14.80) B**	**25.47 (17.13) B**

(Continued)

Table 2 (continued)

Treatment	RI	MI	OI
	Mean (SD)	Mean (SD)	Mean (SD)
EFPEG	40.53 (20.14)	30.80 (21.13)	25.73 (18.45)
NFPG	3.40 (7.39)	3.80 (5.02)	13.67 (15.99)
PH	11.80 (20.01)	2.60 (3.09)	2.93 (2.81)
EPH	0.27 (1.03)	0.00 (0.00)	0.40 (1.55)
BS	30.07 (8.73)	27.93 (9.67)	23.20 (17.49)
Litter	25.40 (13.65)	38.60 (18.20)	43.80 (14.69)
Richness	12 (7.09)	11 (4.58)	10 (4.58)
Shannon-Weaver	1.42 (0.46)	1.43 (0.53)	1.45 (0.74)

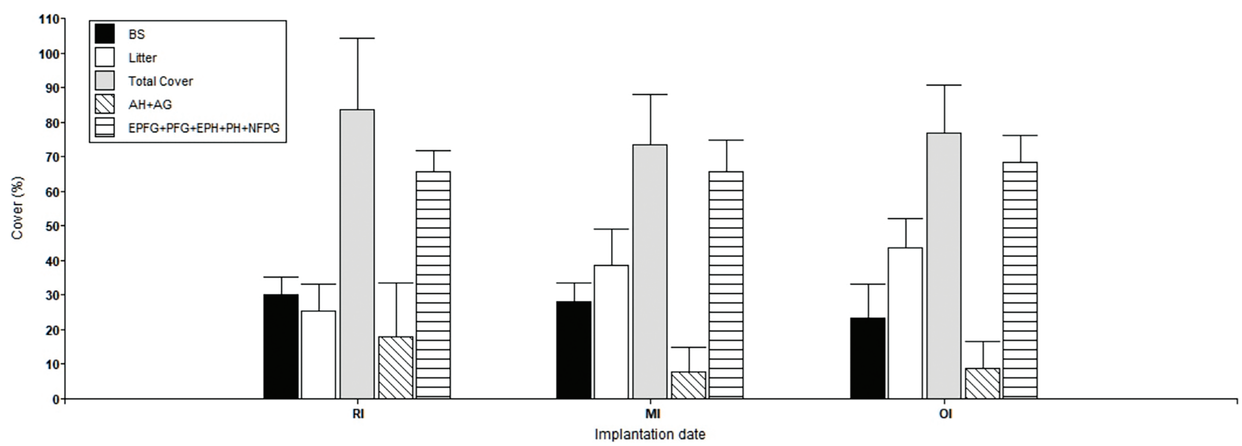

Figure 3: Cover (%) of bare soil, litter, total vegetation, annual and perennial species as a function of implantation date. Note: BS, bare soil; AH, annual herbs; AG, annual grasses, EPFG, exotic perennials forage grasses; PFG, perennials forage grasses; EPH, exotic perennial herbs; PH, perennial herbs; NFPG, non forage perennial grasses

Species richness and Shannon-Weaver diversity index (H’) showed no differences among treatments. Twelve species were recorded in the youngest implantation sites (RI), eleven in the middle-aged ones (MI), and ten in the oldest ones (OI). The H’ values showed the same pattern (Table 1).

The date of establishment did not result in significant differences in terms of litter, bare soil and total cover, not proportion of soil covered by annual or perennial species (Fig. 3). As shown in Table 2, what was statistically significant was the proportion of native or exotic species within the perennial or annual categories, but not their total cover.

4 Discussion and Conclusion

The fact that litter and total cover did not vary among treatments is indicative of the fact that the community of native perennial forage grasses replaced the cover of implanted exotic species. This is desirable in terms of ecosystem rehabilitation and it was the purpose of this study. Our results show that the cover of *Thinopyrum ponticum* decreases with implantation age (Fig. 2). Furthermore, this study demonstrates the potential of native species to establish themselves in old *T. ponticum* pastures and the resilience of semi-arid grasslands to soil disturbance and planting [23]. The reinstatement of natural grassland appears to be a medium-term process, as between 13 and 15 years after the planting of *Thinopyrum ponticum* crops, vegetation cover is predominantly composed of native grassland species (Table 2).

The removal of native plant communities and subsequent use of exotic species can cause environmental damage by altering patterns of ecosystem productivity, nutrient cycling, energy flows, and modifying community composition and structure [24]. Moreover, exotic species can displace native species and prevent them from surviving in new systems dominated by the former [25]. This does not seem to be the case with *Thinopyrum ponticum*, as census data from fields of varying planting ages show an increase in the total cover of PFG and AG.

Several studies conducted in arid and semi-arid areas have also reported a high level of replacement of cover of cultivated perennial species by natives within the first 10–20 years [26–29]. These results imply that recolonization processes in these hostile environments are not slow and show significant changes, resulting in native grass and herb communities within a few years after implantation.

A slight retraction in the cover of the functional group EPFG is observed after years of implantation. This retraction of cultivated species is observed across the MI (15 years old) and OI (>20 years) treatments and may be related to grazing use of these sampling sites and low natural reseeding capacity of the different cultivars of *Thinopyrum ponticum* used in the area [30].

Furthermore, in accordance with our initial hypothesis, there is an increase in species belonging to the functional group perennial forage grasses (PFG) ensuing planting age. This effect, combined with the retreat of AG, results in a change in pasture composition that has a positive effect by generating a more varied and uniform forage supply throughout the year, stabilizing forage production, and covering the soil from erosive effects caused by winds [31].

The rehabilitation of degraded ecosystems results in a community that is different from the original one, which includes arborous and shrubby strata [8], but shows a change towards the reconstitution of native grassland. The use of cultivated exotic species to regenerate native plant communities is considered an alternative to conservation without abandoning the productive use of intervened systems [32]. In seeking to rehabilitate ecosystems that were cleared for extensive dryland agriculture and subsequently abandoned due to loss of profitability, the implantation of *Thinopyrum ponticum* increases soil cover and restores productivity to previously degraded spaces.

The regeneration of natural grassland through perennialization with *Thinopyrum ponticum* could rehabilitate some functions of natural grassland, such as soil cover and net primary productivity of the system. These results contradict our second hypothesis because richness and diversity show no significant differences among implanting ages. However, they are higher compared to the initial monoculture of *Thinopyrum ponticum* and previously bare soil. By reducing the proportion of bare soil, erosion and soil, degradation could be avoided, thereby increasing the provision of ecosystem services. However, the results indicate that, within the studied timeframe, only the cover of grass and herb species were recovered, not the woody layer. Deliberate tree and shrub reintroduction efforts would be necessary to recover these layers.

The results of this study allow us to conclude that some native species in this semi-arid environment have the capacity to re-establish themselves after surface soil disturbance and planting of exotic species. Overgrazing leads to the degradation of these environments, resulting in low-diversity stable states, and applying a disturbance that initiates secondary succession processes could be an alternative for ecological restoration of these systems. In this case, the introduction of a perennial pasture such as *Thinopyrum ponticum* resulted in successions with high diversity and native cover within a period of 13 to 15 years. It is necessary to continue succession studies under different pasture management practices and evaluate environmental factors and interventions that promote the establishment of the shrub layer if restoration of woody vegetation is desired, which could provide environmental goods and services and specific values for conservation.

5 Conclusion

In conclusion, the rehabilitation of native perennial forage species cover is feasible through *Thinopyrum ponticum* implantation. In the future, it would be important to assess the provision of other ecosystem services (water infiltration and retention, soil fertility, etc.) that could be influenced by the perennialization of plots with native species.

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Availability of Data and Materials: The data used for this study will be available via the CONICET repository.

Ethics Approval: Not applicable.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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