

In Search of Sustainable Livestock Management in the Dry Chaco: Effects of Different Shrub Removal Practices on Vegetation and Soil

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Research

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Abstract

Background: In arid and semi-arid ecosystems in Argentina, dominance of shrublands and the search to increase the forage supply for livestock motivates interventions such as roller-chopping and hand-cutting to reduce the abundance of shrubs. However, an integral analysis of the effects of these practices from a sustainability point of view, including not only forage productivity but also other ecosystem service is still missing. We evaluated at the ecosystem level the impact of shrub removal on total production and phenology; at the local level the responses in cover, botanical composition and diversity of vegetation functional groups, as well as the effects on soil physical properties. We combined evaluation methodologies with remote sensing and field sampling in control (woodland, shrubland) and treated (roller chopping, hand cutting) sites in 16 paddocks.

Results: In treated sites, grass cover increased significantly compared to untreated sites. However, total production, growing season length were reduced. Tree cover was lower in treated sites, while shrub cover was reduced in the hand-cutting compared to the other treatments. Forbs cover was not modified. In addition, species richness decreased in the treated sites, being higher in roller-chopped sites than in the hand-cut sites, while the species diversity index was only reduced in the latter type of disturbance. Soil mechanical resistance and bulk density were higher in treated sites, while infiltration rate did not change.

Conclusions: shrub removal and pasture seeding on woodland and shrubland sites increases herbaceous forage production, but decreases total production and increases its temporal variability and rainfall dependence; it decreases functional diversity and increases surface soil compaction. These responses depend on the intensity of the woody biomass removal disturbance (roller-chopping or hand-cutting). In this respect, roller chopping appears to be a more conservative practice than hand cutting, as it maintains high levels of herbaceous forage production and functional diversity. However, it is necessary to consider the importance of maintaining native forest regeneration, as both types of disturbance affected this process. Our study highlights the importance to design selective interventions in the vegetation, compatible with the maintenance of functional diversity, the regeneration of tree strata and the increase in grass production.

Background

Shrub encroachment in arid and semi-arid regions is a global concern (Archer 2010; Rejžek et al. 2017; Chandregowda et al. 2018). The degradation of dry forests and the increase of shrublands during the last century, led to global debates on the causes of this process, where climate change, overgrazing, seed spread by livestock, reduced fire frequency, reduced competition with grasses and increased CO₂ in the atmosphere are some of the causes mentioned (Van Auken 2000; Archer 2010). In addition, the cessation of natural disturbances (Van Auken 2000; Willcox and Giuliano 2010; Archer 2010) could promote shrub establishment and expansion, to the extent of overcoming thresholds where changes in vegetation and soil structure are persistent (Eldridge et al. 2011; Bestelmeyer et al. 2015).

In the Dry Chaco region of South America, the transformation of open woodland into dense shrublands reduces the supply of native grasses, and is therefore often considered a problem for extensive cattle ranching (Adámoli et al. 1990; Fernández and Maseda 2006; Kunst et al. 2012). In general, shrub species compete with native grasses for resources (light and water) and impede the movement of animals and personnel in paddocks due to the high density of branches and thorns (Kunst et al. 2016). The aim to increase grazing areas leads to interventions in native forests and shrublands, where smaller woody strata are removed to reduce competition with forage grasses (Marchesini 2011; Kunst et al. 2016).

In order to reduce the shrub layer and increase the human appropriation of the primary production, biomass removal practices are applied, such as vegetation roller-chopping and hand-cutting (Rueda et al. 2013). Roller chopping is a technique widely used in the Dry Chaco region, in which a heavy cylindrical implement with blades is used, which, when pulled by a tractor, turns and cuts the vegetation (Kunst et al. 2003). It also has a seeding box with which it is possible to sow pastures simultaneously (Anriquez et al. 2005; Marchesini 2011). Hand-cutting, which has a greater impact on the biomass of vegetation than roller-chopping (Tiessen et al. 2003; Marchesini 2011; Kunst et al. 2016), is carried out with tools such as picks, axes and shovels, and generally removes shrubs and their roots, in order to then proceed to sow pastures (Nai Bregaglio et al. 2001).

From the point of view of cattle production, shrubs are often perceived as a problem because of their dominance in the vegetation structure (Kunst et al. 2003; Blanco et al. 2005; Navall et al. 2008; Marchesini 2011). However, they play a fundamental role in regulating various aspects of the ecosystem, such as water and carbon cycles (Huxman et al. 2005; Marchesini et al. 2015; Magliano 2016), spatial heterogeneity (Villagra 2000), soil nutrient supply, habitat preservation for wildlife, among others. In addition, a significant proportion of shrub species have a significant forage contribution (Guevara et al. 2009; Allegretti et al. 2012; Egea et al. 2014). Thus, a dichotomy arises between management strategies that seek to maximize livestock production through the elimination of shrubs and those that promote the conservation of native vegetation and the provision of other ecosystem services, contributing to a more holistic view from the point of view of the sustainability of management. New trends in forest management aim to integrate both approaches through sustainable forest management (Villagra and Alvarez 2019).

Several studies show that at the regional level the conversion of woodlands to pastures, by removing shrubs, generated significant changes in soil physical and chemical parameters, such as decreased infiltration rate and increased bulk density, mechanical resistance and organic carbon (Tiessen et al. 2003; Stavi et al. 2008; Magliano et al. 2017; Somovilla Lumbreras et al. 2019). It also, modifies the seasonal dynamics of carbon fixation, amplifying seasonality and dependence on soil moisture pulses (Nosetto et al. 2020). Finally, this type of disturbance often implies changes in various ecosystem services (regulatory, provisioning, cultural, etc.) such as forage production for domestic livestock (Blanco et al. 2005; Marchesini 2011; Steinaker et al. 2016).

We postulate that different management practices applied in the Dry Chaco, which include shrub removal, alter above-ground primary production and its seasonal distribution (ecosystem phenology), as well as soil physical properties associated with modifications in the composition and dominance of vegetation functional groups. We propose, then, that lower intensity shrub removals offer a better balance between increased herbaceous above-ground primary production (main source of forage) and higher levels of maintenance of functional diversity and soil structure. Thus, sites with higher intensity shrub removal are expected to have more available forage, due to increased herbaceous cover, but lower total above-ground primary production; greater temporal variability of above-ground net primary production with more pronounced seasonality; loss of functional groups with decreased diversity; and increased soil compaction, thus decreased infiltration rate.

We evaluated the effects of mechanical and manual shrub removal (roller-chopping, hand-cutting): i) at the functional level, on aerial above-ground primary production and phenology, analysing the seasonal behaviour of the Normalized Difference Vegetation Index (NDVI) derived from MODIS images, and its relationship with rainfall; ii) at the structural level, on the cover, botanical composition and diversity of functional groups of vegetation; iii) on the physical properties of the soil. For this purpose, remote sensing analyses, vegetation censuses and soil sampling were carried out 5 years after the treatments were applied.

Methods

Study area

The study was carried in the province of La Rioja (Argentina), within the Dry Chaco biogeographic district, also denominated as Western Chaco Park (Ragonese and Castiglioni 1968). According to Oyarzabal et al. (2018) the plains of La Rioja are part of the vegetation unit called "xerophyte forest with *Aspidosperma quebracho blanco* in transition to steppe". The study sites were within a single ecological site denominated "Afloramiento de Cerrillos" (Calella and Corzo 2006) (Fig. 1). The rainfall regime is monsoonal, with a mean annual precipitation of 387 mm, considering the period 1979-2018. In addition to the high rainfall seasonality (82% concentrated between November and March) there is a high inter-annual variability. The temperature reaches maximum values between November and January, and minimum values between May and July, with a monthly average of the warmest month of 28 °C and absolute maximums of 48 °C. The average annual temperature is 20 °C (Blanco 2017).

The soils are associated with different physiographic units and show varying degrees of development, being soils in the plains well developed and with a moderate supply of nutrients. They are classified as typical Torriortents, typical Haplargids, typical Cambortids and lithic Natrargids (Calella and Corzo 2006).

The original landscape is a woodland with three strata of vegetation (tree, shrub and herbaceous). The tree layer is sparse with isolated individuals of white quebracho (*Aspidosperma quebracho blanco*), algarrobo (*Prosopis flexuosa*) and tentitaco (*Prosopis torquata*). The shrub layer is dense with species

such as lata (*Mimozyanthus carinatus*), tusca (*Vachellia aroma*) and jarilla (*Larrea divaricata*). The herbaceous layer is discontinuous with perennial species such as *Leptochloa crinita*, *Gouinia paraguayensis*, and *Digitaria californica*, among others (Ragonese and Castiglioni 1968; Biurrun et al. 2015). However, shrubland is currently the dominant physiognomy of the landscape, as a result of woodland degradation. For several decades (1901-1980) the region was subjected to a process of timber and firewood extraction, mainly of *Aspidosperma quebracho blanco* and *Prosopis flexuosa* trees, both species were required by the railway industry, while the shrubs were used for charcoal production. Changes in the national energy structure and the depletion of the forest stands caused extractive activity to decline a few years later (Natenzon and Olivera 1994). Overgrazing by domestic livestock, coupled with intensive timber and firewood extraction processes, favored the dominance of shrublands in later decades (Biurrun et al. 2015).

Sampling design

The cover types (treatments) evaluated were: woodland (W), shrubland (S), roller-chopping (R) and hand-cutting (H). The roller chopping treatment was carried out in 2013. The hand cutting treatment was performed between 2008 and 2010, with "clearing" of young woody plants in 2013. In addition, to the reduction of woody cover, the roller chopping and hand cutting treatments included the sowing of buffelgrass (*Cenchrus ciliaris* variety Texas 4464).

The evaluations were conducted on a total of 16 paddocks (4 cover types x 4 replicates) distributed over an area of approximately 600 km² (Fig. 1), with an average paddock area of 260 ha for woodland, 47 ha for shrubland, 43 ha for roller chopping, and 38 ha for hand cutting. The selected paddocks received cattle grazing with average stocking rates of 12-15 ha.UG⁻¹.yr⁻¹ for woodland and shrubland cover types, and 3-5 ha.UG⁻¹.yr⁻¹ for paddocks with roller chopping and hand cutting cover types.

Analysis of above-ground net primary production and phenology from NDVI:

The above-ground net primary production and phenology of the different cover types were characterized on the basis of NDVI, a spectral index relating high absorption at red wavelengths to high reflectance in the near-infrared portion ($NDVI = (\text{near infrared-red}) / (\text{near infrared} + \text{red})$). NDVI is a direct estimator of the absorbed fraction of photosynthetically active radiation, and is used as an estimator of primary production (Prince 1991; Paruelo et al. 1997; Di Bella et al. 2004; Piñeiro et al. 2006). NDVI data were extracted from images provided by the MODIS sensor of the TERRA platform (MOD13Q1 product, temporal resolution: 16 days; spatial resolution: 250m; <https://modis.ornl.gov/globalsubset/>; Accessed 10 Mar 2020). Central "pure" pixels of each cover type were selected. The analysis contemplated 5 annual periods (2013-2018) considering each period between September and August, taking into account that the minimum NDVI in the Dry Chaco occurs at the end of August (Zerda and Tiedemann 2010).

To describe the seasonal dynamics of NDVI, the free software TIMESAT was used to evaluate NDVI time series and estimate phenological attributes (Jönsson and Eklundh 2004). The Savitzky-Golay polynomial filter function was used to fit growth models and suppress extreme values. Thresholds for the beginning and end of each growth period were defined when NDVI reached 20% of the seasonal amplitude. Seven attributes that characterize aspects of vegetation phenology were estimated: date of the beginning of the growing season, date of the end of the growing season, length of the growing season, date of occurrence of the maximum annual NDVI, maximum annual NDVI value, minimum annual NDVI value, and annual NDVI integral. It should be taken into account that in TIMESAT outputs, the date format is in Julian days and that they are in relation to the beginning of the period analyzed (start date: September 2013).

Finally, the coefficient of inter-annual variation of NDVI was calculated, $CV\text{-}NDVI = (\text{standard deviation}/\text{mean}) \times 100$.

To estimate the woody and herbaceous contributions to NDVI, the method of disaggregating time series of spectral vegetation indices was used (Lu et al. 2003). This methodology is based on the STL (seasonal-trend decomposition based on LOESS) procedure proposed by Cleveland et al (1990) for time series with a strong seasonal trend. The decomposition of NDVI into its woody (NDVI_w) and herbaceous (NDVI_h) components was applied in the Dry Chaco in previous studies (Blanco et al. 2016; Blanco, 2017).

Determination of precipitation from remote sensors

Satellite-estimated monthly cumulative precipitation data from the Tropical Rainfall Measuring Mission (TMR) available on the Giovanni platform were used (<https://giovanni.gsfc.nasa.gov/giovanni/>; accessed 5 Dec 2020). The TRMM 3B43 v7 product was used. In the platform viewer, areas of interest were selected, coinciding with the pixels where NDVI data were also obtained. For sites with proximity of less than 1 km (e.g. woodlands near shrublands) the same precipitation values were considered for the analysis.

Determinations in vegetation

Using the modified point quadrat method (Passera et al. 1986), cover and botanical composition were determined by vegetation functional group (trees, shrubs, grasses and forbs) and species at the end of the growing season (March-April 2020). In each of the 4 replicates for each cover type, 3 linear 50 m transects were established and needle readings were taken every 0.5 m for a total of 100 points. In each replicate, sampling was located in representative areas of each cover type, avoiding the vicinity of wire fences and cattle trails. The richness and abundance-cover data were used to calculate the Shannon and Weaver (1949) diversity index for each replicate of cover types.

Soil physical determinations

The mechanical resistance of the soil was estimated using a penetrometer, carrying out 5 determinations per replicate for depths of 15, 30 and 45 cm. The bulk density of the soil was determined using the method of Grossman et al (1968), as an indicator of soil porosity, aeration and drainage capacity. Samples were taken at depths of 5 and 15 cm, every 25 m in a linear transect of 250 m in each paddock (10 samples per depth and per replicate). The infiltration rate was determined using the double-ring method (Wilson and Luxmoore 1988), which consists of burying two rings of different diameters in the soil, filling them with water and measuring the variation in the height of the water in the central ring at regular time intervals until the saturated hydraulic conductivity is reached. This measurement was carried out at low volumetric soil moisture (2-4%), during the months of July-August 2019. Two infiltration rate determinations were carried out in each replicate. A soil measurement was carried out in the same areas selected for the vegetation determinations.

Data analysis

Parameters extracted from the fitted NDVI curves were compared through analysis of variance with repeated measures, analyzing effects of time (n=5 years), cover types and their interaction. The relationship between NDVI and precipitation was analyzed by simple linear regression. Comparison of cover, species richness and diversity of species and vegetation functional groups (trees, shrubs, grasses and forbs) between treatments was performed by one-way ANOVA. Soil physical properties were subjected to analysis of variance, with repeated measures in space for mechanical resistance (depths of 15, 30 and 45 cm) and bulk density (depths of 5 and 15 cm), and repeated measures in time (1-120') for infiltration rate. The data for the latter variable were transformed to square root (\sqrt{x}) to meet the assumptions required by the method of analysis. Factors include in the analysis were depth (for mechanical resistance and bulk density) or time (for infiltration rate), cover type, and the interaction between them. In all cases, the significance level was $P < 0.05$ and Duncan's test was used as a post hoc test. Analyses were performed with the statistical software InfoStat v. 2018 (Di Rienzo et al. 2018).

Results

Seasonal dynamics of above-ground net primary production and phenology:

The dynamics of the normalized difference vegetation index (NDVI) differed between cover types for the period analyzed (2013-2018; Fig. 2a). In general, it was observed that NDVI values were higher in cover types without woody removal (being higher in woodland than in shrubland), compared to cover types with woody removal (being higher in roller chopping than in hand cutting). A more uniform overall behaviour in NDVI dynamics was observed throughout the series for sites with a high woody cover, with a coefficient of inter-annual variation (CV-NDVI) of 6% in woodland and 5% in shrubland. Roller chopping and hand cutting had a CV-NDVI of 10% and 12% respectively. It was observed that the seasonal variation of NDVI is associated with the seasonality of rainfall in all cover types (Fig. 2b), with NDVI values increasing from

September-October and decreasing from March-April. The inter-annual variability of NDVI also seems to be affected by the amount of precipitation. Thus, it is observed that all cover types presented lower NDVI values during the periods 2014-2015 and 2017-2018, the drier periods during the study (Fig. 2).

Complementarily, the analysis of the relationship between the annual NDVI integral and annual rainfall showed that both woodland and shrubland primary productions are more independent of rainfall, with R^2 of 0.06 and 0.21 respectively. In contrast to this, we found a high relationship with rainfall for roller chopping and hand cutting sites, the R^2 being 0.27 and 0.38 respectively (Fig. 3).

Phenological attributes associated with seasonal NDVI trends allowed further visual analysis of the impact of woody plant removal on ecosystem functioning. Integral-NDVI was significantly decreased by woody plant removal ($P<0.0001$). The highest losses were observed in hand-cutting, which also had significantly lower values than roller-chopping (Table 1).

The date of the beginning of the growing season did not differ between cover types ($P=0.6704$), but the date of the end of the growing season did ($P<0.0001$). The end of the growing season was earlier in the woody-plant removal cover types, being 30 days earlier in the hand-cutting than in the roller-chopping (Table 1). The length of the growing season was also significantly reduced ($P=0.0177$) in the hand-cutting compared to the rest of the cover types (Table 1), and was similar between shrubland, woodland and roller-chopping. The date of maximum NDVI (March) was similar between cover types ($P=0.6521$; Table 1).

The maximum annual NDVI value was different between cover types ($P=0.001$). In woodland and shrubland, the observed values were similar, and significantly higher than those of roller-chopping and hand-cutting (Table 1). The minimum annual NDVI also showed significant differences ($P<0.0001$), being maximum in woodland and minimum in hand-cutting (Table 1).

Finally, the results in Table 1 show that the interaction cover type*time was significant ($P<0.05$) in the parameters peak value ($P=0.006$), base value ($P=0.0139$) and annual integral-NDVI ($P=0.001$). Therefore, there was a different response between years for the different cover types in these parameters.

Table 1

Mean values and standard deviation of attributes estimated from the NDVI seasonal trend (period 2013-2018) for the cover types: woodland, shrubland, roller-chopping and hand-cutting. Different letters indicate significant differences ($P<0.05$) between means of the cover types (Duncan post hoc test).

	Woodland	Shrubland	Roller-chopping	Hand-cutting	P value
Annual Integral NDVI	5.41±0.76 (a)	4.93±0.51 (b)	4.19±0.65 (c)	3.43±0.61 (d)	Treatment (<0.0001) Year (0.0001) Interaction (0.001)
Start -growing season	27 oct ±32 days	25 oct ±37 days	28 oct ±44 days	06 nov ±48 days	Treatment (0.6704) Year (<0.0001) Interaction (0.7203)
End-growing season	01 jul ±15 days (a)	23 jun ±26 days (a)	7 jun±20 days (b)	01 may ±12 days (c)	Treatment (<0.0001) Year(<0.0001) Interaction (0.0502)
Length-growing season	274 ±25 days (a)	265 ± 32 days (a)	250 ±42 days (ab)	225 ± 40 days (b)	Treatment (0.0177) Year (0.0093) Interaction (0.5025)
Date NDVI maximum	18 mar ±34 days	18 mar ±33 days	15 mar ±38 days	23 mar±31days	Treatment (0.6521) Year (<0.0001) Interaction (0.3158)
Max. annual NDVI	0.63±0.07 a	0.61±0.07 a	0.55±0.1 b	0.48±0.09 c	Treatment (0.0001) Year (0.0025) Interaction (0.006)
					Treatment

Min. annual NDVI	0.38±0.03 (a)	0.33±0.02 (b)	0.28±0.01 (c)	0.23±0.02 (d)	(<0.0001) Year (<0.0001) Interaction (0.0139)
Coefficient of variation-NDVI	6%	5%	10%	12%	

The disaggregation of NDVI into herbaceous (NDVI_h) and woody (NDVI_w) components revealed changes in the functionality of the cover types evaluated. Thus, NDVI_h was different between cover types ($P<0.009$). The cover types with shrub removal treatment (roller-chopping and hand-cutting) presented significantly higher values than the woodland. NDVI_w also showed significant differences between cover types ($P<0.001$), being higher in woodland, and gradually decreasing towards shrubland, roller-chopping and hand-cutting respectively (Fig. 4).

Cover, botanical composition and diversity of vegetation functional types

Vegetation functional group cover showed differences between cover types with and without shrub removal. Trees were the functional group most affected by woody-plants removal ($P<0.0006$; Fig. 5), with higher cover in the woodland (24%) and shrubland (16%) than in the roller-chopping (3%) and hand-cutting (2%). This functional group was represented in greater proportion by *Aspidosperma quebracho blanco* in the woodland, *Prosopis torquata* in the shrubland and roller-chopping, and *Prosopis flexuosa* in the hand-cutting (Table 2). Although shrub cover differed between cover types ($P<0.0008$), only hand-cut showed significant differences with respect to the other treatments evaluated (Fig. 5). In the woodland, shrubland and roller chopped, the dominant shrubs were *Larrea divaricata*, *Mimozyanthus carinatus*, and *Cordobia argentina* (Table 2), while in the hand-cutting the dominant species was *Vachellia aroma* and those mentioned above did not have a significant participation.

Grass cover increased after shrub removal, and significant differences were found between cover types ($P<0.0001$). Thus, in the hand-cutting and roller chopping sites the grass cover was 84% and 44% respectively, while in the cover types without woody-plants removal (woodland and shrubland) the grass cover was significantly lower (14% and 28%, respectively). The increase in grass cover in roller-chopping and hand-cutting sites was not only associated with woody removal but also with the sowing of the non-native grass *Cenchrus ciliaris*. In hand-cutting sites 100% of the grass cover, while in roller-chopping sites the 50%, corresponds to the sown species (Table 2). The two grass species that sowed different cover between woodland and shrubland were *Digitaria californica* and *Gouinea paraguayensis* (Table 2).

Finally, forbs did not show significant changes between sites with and without shrub removal ($P=0.1466$). However, at the species level, it was observed that *Sida argentina* was the only forbs species present in

the hand-cutting. *Pseudabutilon virgatum* had a higher cover in shrubland than in the other treatments (P=0.020; Table 2).

On the other hand, species richness and diversity showed differences between cover types (P<0.0001). Species richness decreased significantly in sites with shrub removal, being higher in the roller-chopping than in the hand-cutting (Table 2). Species diversity was significantly lower in the hand-cutting than in the other cover types (Table 2).

Table 2

Mean (%) cover and standard deviation of species by functional group, total richness and Shannon Diversity index, for the cover types: woodland, shrubland, roller-chopping and hand-cutting. Values are only shown for species with constancy greater than 25% between surveys. Different letters indicate significant differences (P<0.05) between means of the cover types (Duncan post hoc test).

	Woodland	Shrubland	Roller-chopping	Hand-cutting	P value
Trees	17.9 ±3.8 (a)	0.0 (b)	0.0 (b)	0.0 (b)	0.001
<i>Aspidosperma quebracho-blanco</i>					
<i>Prosopis torquata</i>	6.0±6.1 (b)	13.4±2.1 (a)	3.4±2.7 (bc)	0.0 (c)	0.001
<i>Prosopis flexuosa</i>	1.8 ±1.3 (a)	2.3 ±1.6 (a)	0.0 (b)	1.8±0.6 (a)	0.040
Shrubs					
<i>Larrea divaricata</i>	14.8±6.4 (a)	15.7 ±4.6 (a)	16.9±4.2 (a)	0.0 (b)	0.001
<i>Cordobia argentina</i>	8.4±13.3	15.9±9.4	7.8±9.5	0.0	0.181
<i>Mimozgyanthus carinatus</i>	5.6±8.7	0.6±1.2	3.1±2.3	0.0	0.334
<i>Celtis chichape</i>	5.2±5.2	0.7±1.4	1.4±1.7	1.2±0.9	0.158
<i>Parkinsonia praecox</i>	4.7±5.4	0.4±0.7	1.6±1.3	0.0	0.130
<i>Atamisquea emarginata</i>	4.6±5.0	0.3±0.6	0.0	0.0	0.062
<i>Monteverdia spionosa</i>	1.8±0.8 a	0.0 b	0.0 b	0.0 b	0.001
<i>Senna aphylla</i>	0.9±1.5	0.5±0.4	0.5±1.1	0.0	0.568
<i>Aloysia gratissima</i>	0.9±0.8	2.0±2.8	2.5±4.0	0.7±1.4	0.714
<i>Lycium elongatum</i>	0.4±0.8	0.4±0.4	1.7±2.0	0.0	0.183
<i>Vachellia aroma</i>	0.0 b	0.0 (b)	0.4±0.8 (b)	9.4±1.2 (a)	0.001
Grasses					
<i>Leptochloa crinita</i>	4.1±3.0 (a)	11.2±6.4 (ab)	4.4±5.5 (ab)	0.0 (b)	0.029
<i>Setaria pampeana</i>	3.3±0.6 (a)	3.4±0.6 (a)	2.2±2.8 (ab)	0.0 (b)	0.021
<i>Sporobolus pyramidatus</i>	2.2±2.7	0.0	4.8±8.2	0.0	0.381
<i>Digitaria californica</i>	1.2±0.7 (a)	5.6±3.9 (b)	0.4±0.8 (b)	0.0 (b)	0.008
<i>Pappophorum caespitosum</i>	1.2±1.4	0.5±0.4	0.0	0.0	0.125
<i>Neobouteloua lophostachya</i>	0.9±1.8	0.4±0.4	1.1±2.2	0.0	0.699
<i>Gouinea paraguayensis</i>	0.7±0.8 (b)	4.3±2.5 (a)	4.7±3.7 (a)	0.0 (b)	0.023
<i>Aristida mendocina</i>	0.5±1.1	0.4±0.7	4.2±5.3	0.0	0.158

<i>Leptochloa pluriflora</i>	0.2±0.4	1.9±1.5	1.4±2.9	0.0	0.292
<i>Cenchrus ciliaris</i>	0.0 (c)	0.0 (c)	20.1±12 (b)	84.3±1.9 (a)	0.000
Forbs					
<i>Pseudabutilon virgatum</i>	0.7±0.4 (b)	5.5±3.9 (a)	0.9±0.7 (b)	0.0 (b)	0.020
<i>Sida argentina</i>	0.4±0.4	0.0	2.2±3.5	1±0.7	0.367
<i>Evolvulus arizonicus</i>	0.0	4.2±6.5	0.3±0.6	0.0	0.243
Species richness	21±4 (a)	16.8±3.2 (ab)	14.5±3.4 (b)	4.8±1 (c)	0.000
Shannon–Weaver diversity index	2.5±0.1 (a)	2.3±0.2 (a)	2.2±0.3 (a)	0.6±0.1 (b)	0.000

Effects in soil physical properties

The evaluation of soil physical parameters showed that woody-plants removal generated significant changes with respect to cover types without woody-plant removal ($P=0.0491$). The mechanical resistance showed similar mean values for woodland (3.8 MPa), shrubland (3.6 MPa) and roller-chopping sites (3.5 MPa), but was significantly ($P<0.05$) higher for hand-cutting sites (4.2 MPa). In addition, it was observed that in sites without shrub removal, resistance increased with depth, while in sites with shrub removal, it decreased (Figure 7a, interaction cover type*depth, $P<0.0001$).

With respect to bulk density, higher compaction was observed in the hand-cutting (1.5 g/cm³), compared to woodland, shrubland and roller-chopping sites ($P=0.002$; Fig. 6b). The cover type*depth interaction was also significant ($P=0.0192$; Fig. 6b): in woodland the bulk density was similar between depths, while in shrubland, roller-chopping and hand-cutting it was higher at 5 cm depth (surface compaction).

With respect to infiltration rate, no statistically significant differences were found between treatments ($P=0.2521$) or in the treatment*time interaction ($P=0.7979$), but there was a significant effect of time ($P<0.0001$) (Fig.6c).

Discussion

The dominance of shrubs is one of the main challenges facing livestock farming in the Dry Chaco, where roller-chopping and hand-cutting are alternatives widely used by livestock producers. Consistent with expectations, the higher the intensity of shrub removal, the lower primary production and the higher inter-annual variability for this variable; but at the same time shrub removal provides a greater supply of forage as grasses, sustained by an increase in the abundance of sowed pastures. In addition, it generates changes in the dynamics of the vegetation growth and in the times of maximum production. On the other hand, it modifies aspects related to the functional diversity of the vegetation, such as botanical

composition, species richness and functional groups and species cover. The shrub layer is greatly affected, although in the roller-chopping treatment the regeneration capacity is high, at difference to hand-cutting treatment where a change in dominant woody species is observed. One aspect to consider is the reduction of the tree layer, an undesirable situation that needs to be reviewed in the two shrub removal treatments. Soil physical properties are also worsened by shrub removal treatments.

In this study we raised five key issues to discuss about the effect of removing shrubs and incorporating grasses: a) maintains whole vegetation cover but decreases total primary production; b) increases temporal variability of primary production and their dependence on rainfall; c) generates changes in the structure, floristic composition and diversity of vegetation; d) shrubs have the capacity to regenerate; e) modifies the physical properties of the soil.

a) Maintains whole vegetation cover but decreases total primary production

Time series analysis of NDVI showed that in sites with shrub removal, NDVI decreases significantly compared to sites with a higher proportion of woody species (woodland and shrubland). Shrub removal increases the fraction of absorbed photosynthetic active radiation (fAPAR) contributed by the herbaceous component (grasses and forbs) to the total NDVI, and decreases that of the woody component (trees and shrubs), evidencing changes in the abundance of these functional groups. Due to the linear relationship between fAPAR and net aboveground primary production (Pettorelli et al. 2005; Paruelo 2008), it was found that in sites where woody vegetation was reduced, total production is lower. Furthermore, this index only considers the green fraction of the vegetation, so if the non-photosynthetic fraction (branches, woody stems, etc.) that is removed by mechanical and manual control is included, the differences would be greater compared to undisturbed sites (Marchesini 2011).

In this study, at the farm scale, we found a significant increase in grass cover with the roller-chopping and hand-cutting treatments. At the ecosystem level, the disaggregation of NDVI time series reflected the increase in the NDVI integral of the herbaceous component in the treated sites, but changes in the productivity of these functional groups were less sensitive to those detected in the field. As reported by Blanco (2017) growth rate, senescence, and the timing of the onset and end of growth do not vary significantly between native grass species such as *Pappophorum caespitosum*, and the sowed grass *C. ciliaris*. This could partly explain why changes in grass cover were less sensitive to detection with methods based on the use of spectral indices. In contrast, the decrease in the NDVI integral of the woody component followed the same trend as shrub cover detected in the field.

The lower values in the annual integral of NDVI (estimator of the fraction of photosynthetic radiation absorbed) observed in the roller-chopping and hand-cutting sites could be explained by their lower functional diversity (number of functional groups of vegetation, species richness, etc.). Numerous studies have proven that higher functional diversity of vegetation is positively related to net primary production and carbon sequestration (Tilman et al. 1996; Reich et al. 2001; Díaz and Cabido 2001; Jackson et al.

2002; Grace et al. 2007; Flombaum and Sala 2008). On the other hand, the role of individual species and their contribution to the maintenance of ecosystem services must be considered. For example, Blanco (2017) mentioned that woody tree species, such as *P. flexuosa* and *A. quebracho blanco*, absorb more radiation and are more efficient in their conversion to primary production than many perennial grasses. The removal of these species, together with the increase of shrubs in similar sites in the dry Chaco, led to a reduced supply of grasses and an impoverishment of the system (Marchesini 2011). According to Rueda et al. (2013), the replacement of native vegetation to pastures allows for a higher harvestable fraction of net primary production (e.g. by grazing), but reduces its total value compared to natural systems. Consistent with this pattern, Del Grosso et al. (2008) mentioned that globally net primary production is higher in ecosystems dominated by trees than by grasses. Our results showed that the removal of shrubs and the sowing of *C. ciliaris* maintain total vegetation cover and increase the forage supply for livestock, but do not compensate for the loss of primary production of the woody strata, mainly of trees. In this sense, hand-cutting could maintain a low proportion of woody species and a high proportion of grasses in the medium to long term, although always with lower total production than natural sites. These results are important from a livestock point of view, but also in the context of climate change, with the need to reduce emissions and to increase sequestered carbon.

b) Increases temporal variability of primary production and dependence on rainfall

Primary production determines the energy available for the rest of the trophic levels and its seasonal dynamics is particularly relevant as it synthesizes several aspects of ecosystem functioning (Paruelo 2008). Analysis of NDVI (proxy of primary production) showed that sites with a higher proportion of woody species had higher values of annual integral NDVI and a lower coefficient of inter-annual variation, compared to sites dominated by grasses. Thus, a more even distribution of primary production throughout the year confers positive effects on ecosystem services, such as greater stability of green biomass for herbivores (Volante et al. 2012).

The changes in the seasonal dynamics observed in the sites with shrubs removal generated a shortening of the growing season and an earlier end time, coinciding with the results reported by Marchesini (2011) and Steinaker et al. (2016). These changes are related to a lower density of trees and shrubs, which have a longer growing period than herbaceous species (Blanco 2017). In addition to the fact that woody-dominated sites showed greater stability in annual primary production, they also showed less dependence on rainfall events compared to grass-dominated sites. Thus, the replacement of woodland to pasture generates changes in various aspects of ecosystem functioning, such as water and carbon cycling (Steinaker et al. 2016; Magliano 2017). In general, the greater the structural difference between native vegetation and the vegetation it is replaced by, the greater the functional changes (Volante et al. 2012).

Nosetto et al. (2020) find that dry forests in the Dry Chaco have higher net carbon gain than pastures, because they have higher primary production and this variable is less sensitive to drought when the

proportion of woody species is dominant. Thus, ecosystem resilience and resistance to biomass removal disturbances is strongly influenced by the traits of the dominant species. Communities dominated by fast-growing species (e.g. grasses) tend to have higher resilience and lower resistance, with the opposite occurring when the dominant species are slow-growing (e.g. woody) (MacGillivray et al. 1995). Our findings are consistent with this pattern of vegetation responses, with clear differences between sites dominated by *C. ciliaris* and those dominated by woody species.

We found that the annual integral NDVI shows differences in the relationship with precipitation depending on the cover types. Thus, in the roller-chopping and hand-cutting sites (dominated by grasses), the NDVI integral showed a higher relationship (R^2) with rainfall than in the woodland and shrubland sites (dominated by woody species). Similar results were reported by Zerda and Tiedemann (2010), where they find that there is greater stability in NDVI in woodland sites than in grasslands. This pattern is a consequence of the fact that woody species are generally more independent of rainfall, as they have deep roots with access to water from lower soil horizons, while grasses with shallow roots, only experience growth pulses linked to events of rainfall and soil moisture in the upper horizons (Schwinning and Sala 2004; Villagra et al. 2011). However, climate change and intense biomass removal disturbances can generate profound temporal mismatches between resource pulses and the consumers of those pulses, impacting various ecosystem processes (Schwinning and Sala 2004).

c) Generates changes in the structure, floristic composition and diversity of vegetation

The removal of shrubs modified the structure, floristic composition and diversity of the vegetation, transforming a system dominated by tree and shrub species to one dominated by grasses. We found a high regeneration capacity of the shrub layer and a low regeneration capacity of the tree layer after roller chopping, which is consistent with the results reported by Steinaker et al (2016). Juvenile trees are damaged by this treatment because it is not a very selective practice, in which only large trees are left (Navall 2008). It should be considered that many tree species in the forests of the Dry Chaco, such as those of the *Prosopis* genus, are a source of food with a high content of sugars and proteins for small ruminants (Villagra et al. 2000) and are therefore important from a forage point of view. Kunst et al. (2012), mention that the implantation of *Megathyrsus maximus* cv. *Gatton panic* in roller-chopping sites, maintains the accessibility of paddocks as it is a good competitor with woody seedlings. Our findings suggest that the same may be true for tree species, which may also be under increased grazing pressure due to intensification of grazing. Thus, for example, mortality of juveniles (< 20 cm diameter) of *A. quebracho blanco* creates a gap of approximately 85 years in forest structure (Navall et al. 2008), where the elimination of nurse plants may also be one of the causes (Barchuk et al. 2008), beyond the damage generated by mechanical or manual control. Hand-cutting, on the other hand, also leaves a minimal proportion of adult trees, while regrowth is frequently eliminated during "clearing" practices, preventing the recruitment of individuals in higher diameter classes (Nai Bregaglio et al. 2001). In our study area, we found that this type of intervention allows the establishment of buffelgrass, but affects the regeneration of trees and native forage grasses that cannot compete for resources with this pasture. However, Nai

Bregaglio et al. (2001) found that manual thinning, when carried out preserving forest species such as *A. quebracho blanco* and *P. flexuosa* allows a high production of natural grassland, as well as woodland regeneration, increasing tree density by more than 500%.

On the other hand, the treatments aimed at reducing the shrub layer modified other attributes of the vegetation, such as species richness and diversity. Thus, these variables were lower in the treated sites than in the control sites, with diversity being lower in all cases in the sites subjected to hand-cutting. However, Blanco et al. (2005) found that roller chopping in the short term did not change these attributes after application. In this context, our results suggested, the need to generate strategies for more selective shrub removal and conservation management in the Dry Chaco, which allow the increase of pasture production and the regeneration of native forest (Boletta et al. 2006), as well as the conservation of other ecosystem services, among which soil quality stands out (Silberman et al. 2015).

d) Shrubs have the capacity to regenerate

The removal of shrubs frees up space and increases the availability of soil resources, thereby creating conditions for the establishment of grasses (Fernández and Maseda 2006). However, certain shrub species are able to regenerate their biomass and return to dominate these environments. Our results show a high regeneration capacity of the shrub layer in response to roller-chopping, but not to hand-cutting. In the latter case, the diversity of functional groups, species richness and shrub density is drastically reduced, because only those species that regenerate preferentially through seeds are part of the secondary succession. In the roller-chopping, damaged shrubs regenerate by basal resprout (Bravo et al. 2018), so they do not change their density (Blanco et al. 2005; Marchesini 2011). Although the immediate effect of roller-chopping is to reduce shrub cover, a study show that it "rejuvenates" shrubs, so they recover their pre-disturbance cover within 3–4 years (Kunst et al. 2003). Thus, in the roller-chopping, shrub species with regrowth capacity, such as *Larrea divaricata*, recover their cover and even increase it with respect to the previous woodland or shrubland condition, where it is one of the dominant species. However, when it is entirely removed by hand-cutting, it is replaced by *Vachellia aroma*, a spinescent shrub that establishes mainly from seed.

Hand-cutting appears to be more effective than roller-chopping in reducing shrub populations in the long term, although it is less environmentally sustainable and may negatively impact essential ecosystem services (Kunst et al. 2012). However, some experiences show that selective hand-cutting, in which forage trees and shrubs are preserved, maintains forest regeneration (Nai Bregaglio et al. 2001).

In both types of disturbance, the establishment of pastures seems to be the preferred option to increase the herbaceous forage supply, since they are fast-growing and have a high capacity to compete with shrubs. In the Dry Chaco of La Rioja Province, the increase in forage supply is associated not only with less competition for resources between grasses and shrubs due to the removal of the latter, but also with the simultaneous sowing of *C. ciliaris*, a highly productives species ($> 2500 \text{ kg DM} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) (Blanco et al. 2005), whose implanted area in the study region exceeds 120000 ha (Garay and Aguero 2018). In this context, livestock producers allocate economic resources to increase the areas rolled and planted with *C.*

ciliaris, but there is a lack of plans that consider the regeneration capacity of the shrub layer (Díaz et al. 2007; Bravo et al. 2018). Our results raise the need for a functional approach to strengthen forest management plans, restoration practices, and the development of activities to mitigate climate change (Bravo et al. 2018).

e) Modifies the physical properties of the soil

Shrub removal increased surface soil compaction and there was a tendency to decrease infiltration rate, in agreement with the results described by Magliano et al. (2016) for a sector of the Dry Chaco in the province of San Luis. Mechanical resistance was increased in the hand-cutting treatment, while roller-chopping showed no difference with untreated sites. These results are opposite to those reported by Magliano et al. (2017), where they found a greater impact of roller chopping on this variable, doubling its mean value with respect to the woodland. On the other hand, the surface soil horizon increased its bulk density with the manual treatment, but not with the mechanical one, coinciding with what was described by Anriquez et al. (2005) in rolled sites in Santiago del Estero province. With respect to infiltration rate, Kunst et al. (2003) showed that this variable increases after roller-chopped, although initially there may be a negative effect due to soil compaction caused by the passage of the tractor and the roller. For the study site, we observed that this variable tended to decreased 6 years after roller-chopping. Possibly, the incorporation of organic matter and initial roughness generated by this type of disturbance can improve soil conditions and increase the infiltration rate; however, the effect of increased stocking rate, the impact of heavy rains, the higher density of buffelgrass shallow roots and the lower shrub cover (lower organic matter contribution to soil), could gradually "dilute" the positive effect of roller-chopping in terms of infiltration rate.

As mentioned, several studies in the Dry Chaco highlight the need to integrate woodland conservation practices with livestock management, with selective, low-intensity interventions in the vegetation, which also allow soil quality to be conserved (Anriquez et al. 2005; Blanco et al. 2005; Navall et al. 2008). In this sense, monitoring vegetation dynamics and changes in soil physical and chemical properties allows foreseeing the necessary practices to maintain the ecosystem in a certain stable state, where forage production, conservation of native vegetation and soil quality are possible (Kunst et al. 2012; Fernández and Maseda 2006).

Conclusions

The removal of shrubs and sowing of pastures, in order to increase forage supply for cattle, has impacts on various aspects of the ecosystem. Total production in treated sites is reduced compared to sites with native vegetation, increasing its temporal variability and dependence on rainfall. In addition, also vegetation diversity and soil physical properties are worsened. These ecosystem responses also depend on the intensity of the woody biomass removal practice: roller-chopping seems to be a more conservative practice than hand-cutting, as it maintains higher levels of forage production and functional diversity than hand-cutting. However, the study of selective interventions on vegetation that make compatible the maintenance of functional diversity and the increase of pasture forage for livestock, should be further

studied. In this sense, it is necessary to improve the conservation of the tree species in response to this kind of practices. Finally, it is essential to design plans that contemplate the application and adequate management of disturbed areas (choice of sites, maximum area to be disturbed, frequency and intensity of shrub removal practices, etc.) in order to conserve the functionality for which they were implemented.

Abbreviations

fAPAR = fraction of photosynthetically active radiation absorbed

H= hand cutting

MODIS = moderate resolution imaging spectroradiometer

NDVI = normalized difference vegetation index

NDVI_h= normalized difference vegetation index herbaceous

NDVI_w= normalized difference vegetation index woody

R=roller chopping

S=Shrubland

W= woodland

Declarations

Ethics approval and consent to participate:

Not applicable

Consent for publication:

Not applicable

Availability of data and material:

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests

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Authors' contributions:

All authors contributed to the study conception and design. Material preparation, data collection, and writing initial draft: LMG, DIP, MEP, ARR. Data analysis, writing final version, review and editing: LMG, PEV, REQ and LJB. All authors read and approved the final manuscript.

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Figures

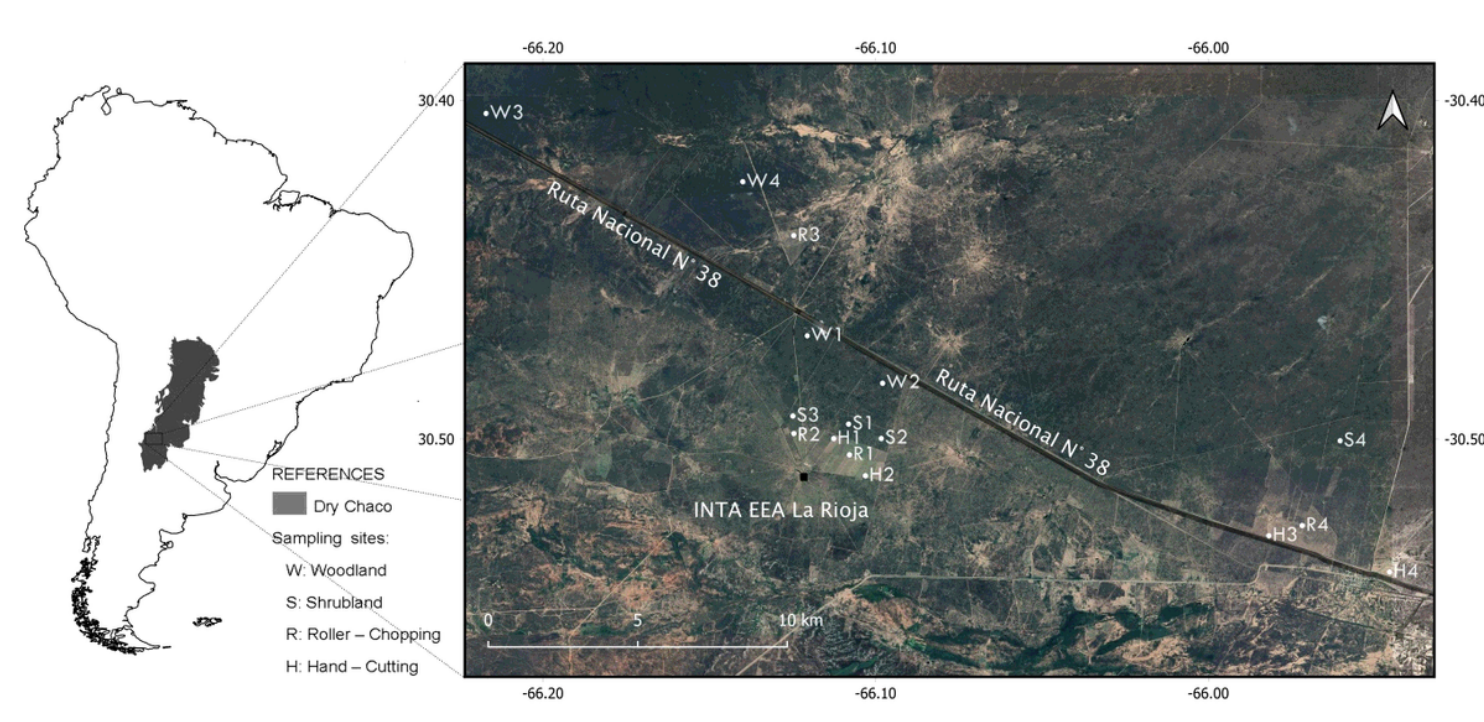


Figure 1

Location of study sites within the ecological site “Afloramiento de Cerillos” in the Dry Chaco region, La Rioja Province, Argentina (Calella and Corzo 2006).

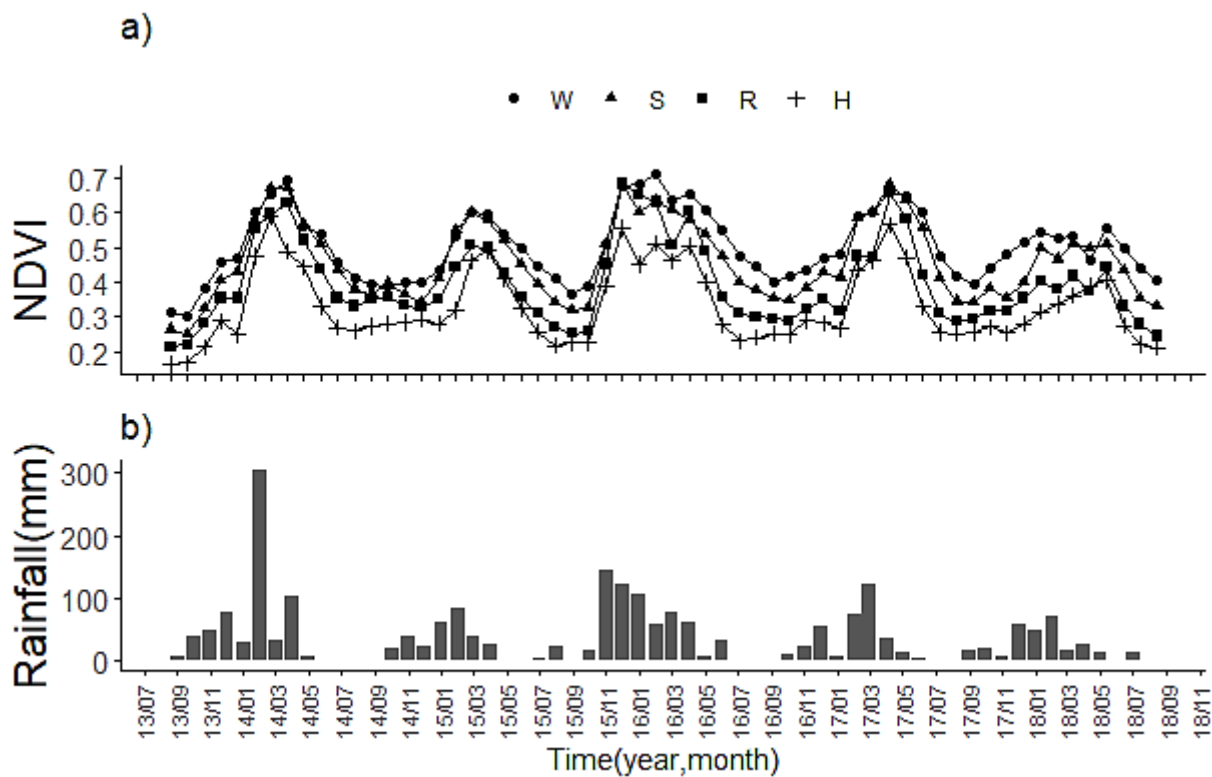


Figure 2

Normalized difference vegetation index (NDVI) dynamics, average values by cover type: a woodland (W), shrubland (S), roller chopping (R) and hand cutting (H) for the period 2013-2018. b Monthly precipitation for the period 2013-2018 (data obtained from the TRMM satellite of the Giovanni platform).

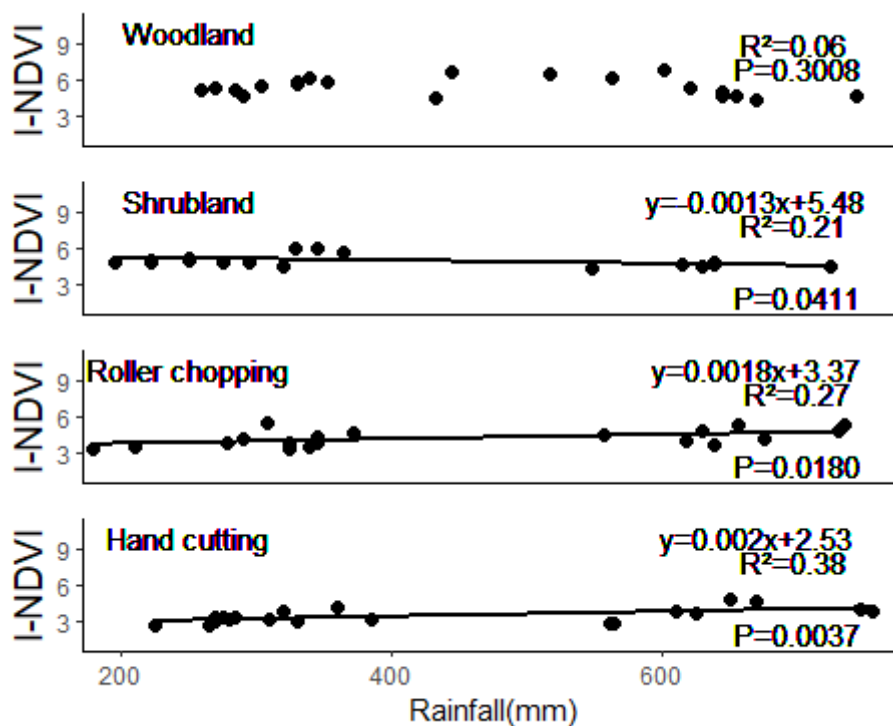


Figure 3

Relationship between annual NDVI integral (I-NDVI) (integrated from September to August) and annual precipitation (accumulated from September to August) by cover type: woodland, shrubland, roller-chopping and hand-cutting.

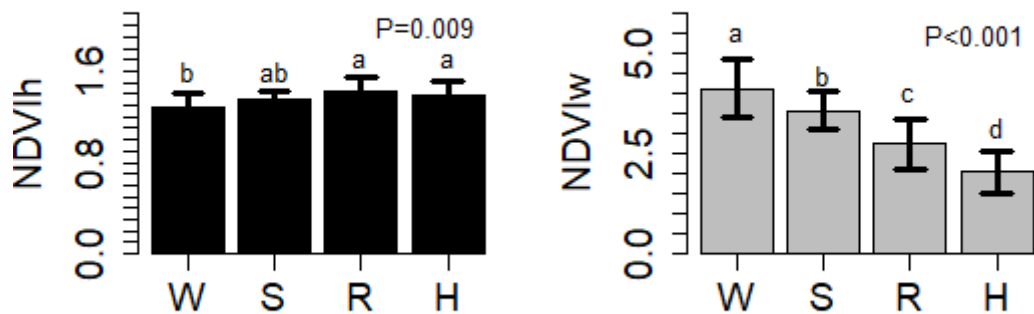


Figure 4

Mean values (bars) \pm 1 standard deviation (lines) of the herbaceous (NDVIh, left panel) and woody (NDVIw, right panel) component of NDVI for the cover types: woodland (W), shrubland (S), roller-chopping (R) and hand-cutting (H). Note that the scales are different. Different letters between bars indicate significant differences ($P < 0.05$) between cover types (Duncan post hoc test). Bars indicate mean values and lines indicate standard deviation.

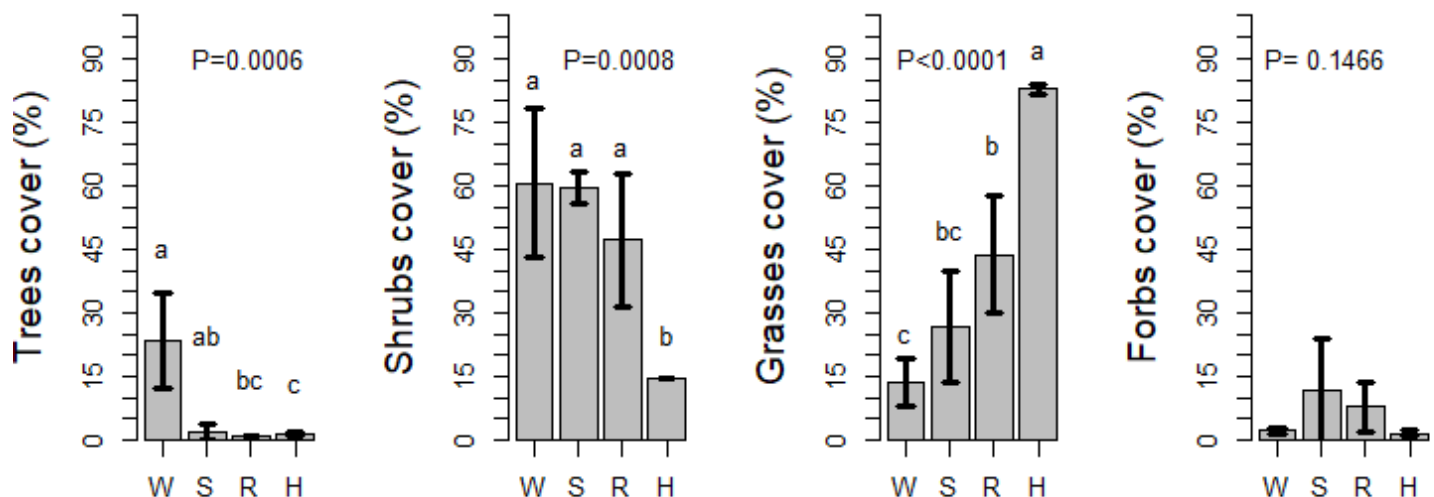


Figure 5

Coverage of vegetation functional groups (trees, shrubs, grasses and forbs) for cover types woodland (W), shrubland (S), roller-chopping (R) and hand-cutting (H). Different letters between bars indicate significant differences ($P<0.05$) between cover types (Duncan post hoc test). Bars indicate mean values and lines indicate standard deviation.

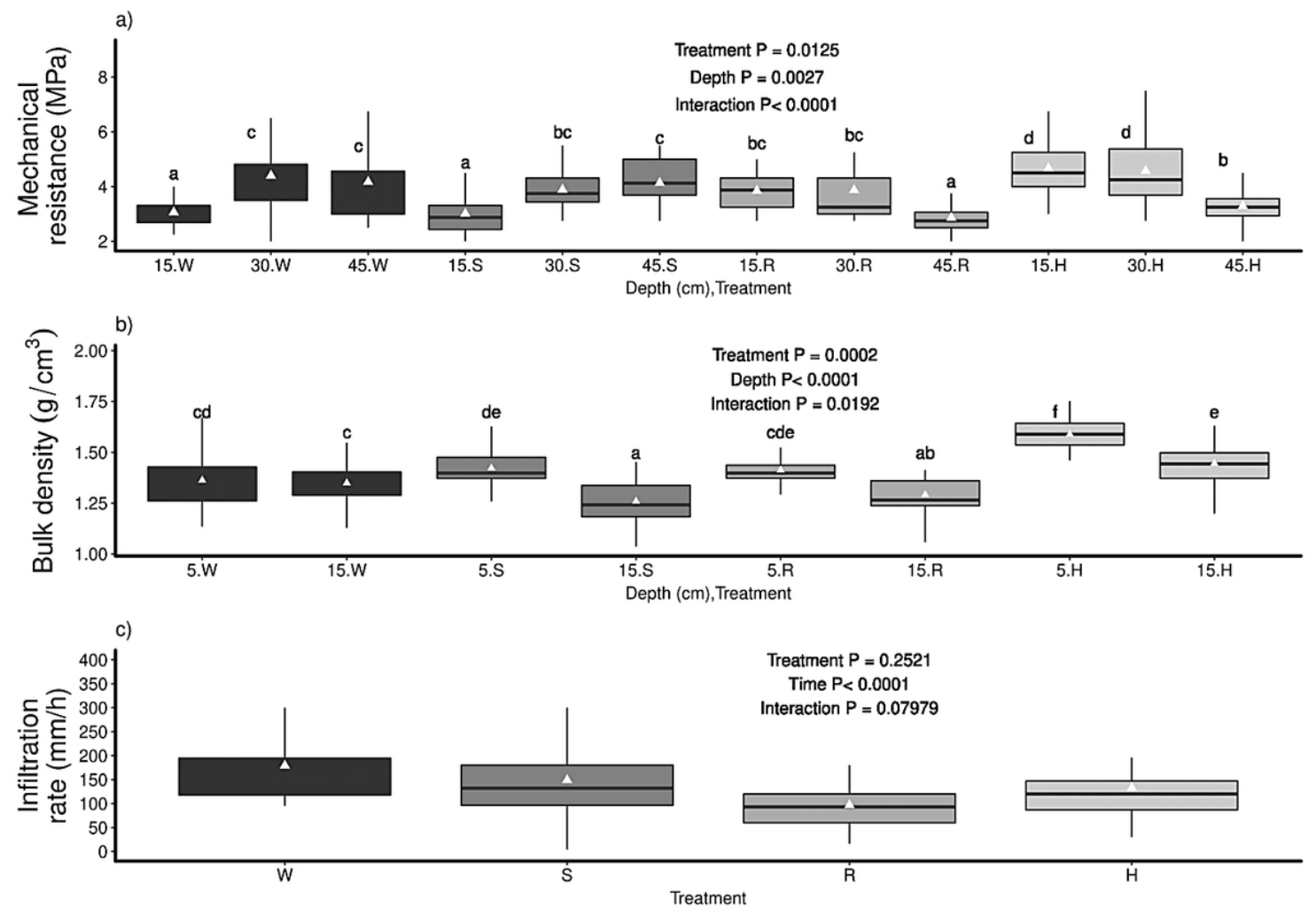


Figure 6

Soil physical properties for cover types: woodland (W), shrubland (S), roller-chopping (R) and hand-cutting (H). Soil mechanical resistance at different depths (15, 30 and 45 cm) a; soil bulk density at different depths (5 and 15 cm) b and infiltration rate c. Boxes represent quartiles 1, 2 and 3; lines represent the 95th and 5th percentile; and triangles represent the mean. Different letters between treatments indicate significant difference ($P<0.05$).