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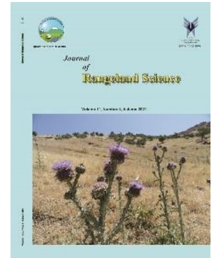

Research and Full Length Article:

The Effect of *Crataegus pseudomelanicarpa* Pojark. Canopy on Soil Total Carbon and Particulate Organic Matter in Grazed and Ungrazed Areas in Alborz Rangelands, Noor County, Iran

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Abstract. Trees and shrubs can act as nurse plants that facilitate the growth and development of other herbaceous species under their canopies and induced the autogenic development of soil parameters. Therefore, we studied the effect of *Crataegus pseudomelanicarpa* on soil carbon sequestration (total soil carbon and particulate organic matter) in two grazed and ungrazed areas during the two seasons (spring and autumn) in central Alborz, Pasperes village, Noor rangelands, Iran. Fifteen individual trees (according to the surface of each region, five in the ungrazed and ten in the grazed areas) were selected. Soil samples were taken in spring and autumn in 2017 under woody canopy (patch) and outside the canopy (interpatch) of individual trees. Soil samples were tested for Total Carbon (TC) and Particulate Organic Matter (POM). The results showed that the value of TC was higher in the autumn than the spring and conversely, POM was significantly higher in spring than autumn. Generally, the results showed that the presence of the shrubs in both grazed and ungrazed areas improved the values of TC and POM in both seasons. In the grazed area, POM (24.43 g kg^{-1} vs. 15.41 g kg^{-1} in the spring and 11.71 g kg^{-1} vs. 8.59 g kg^{-1} in the autumn) and TC (1.53% vs. 1.35% in the spring and 1.61% vs. 1.58% in the autumn) had significantly higher values in patches than interpatches while in the ungrazed area, these differences were less pronounced or not significant between patches and interpatches. It was concluded that the facilitated role of woody species in the conservation of soil carbon is more prominent in the grazed compared with ungrazed grasslands. It emphasized conservation of woody species in the rangelands particularly in the grazed areas.

Key words: Nurse plants, Soil parameters, Subalpine grasslands

Introduction

It has been continuously reported that grasslands play an important role in providing effective ecosystem services. However, unfortunately, the degradation of these ecosystems is globally occurring due to human activities and poor management such as intensive livestock grazing (Loydi *et al*., 2012). Overgrazing is regarded as a dominant factor in causing grassland degradation (Akiyama and Kawamura, 2007). However, overgrazing degraded not only aboveground vegetation, but also the soil in the grasslands. It has been accepted that animal grazing is able to alter the cycles of soil carbon, nitrogen and other nutrients in grassland ecosystems by the interactions between plants and the soil (Wu *et al*., 2009). Particularly, overgrazing dramatically deteriorated soil properties such as total soil organic carbon (SOC) (Follett and Reed, 2010).

Woody plant species can act as nurse plants that facilitate the growth and development of other herbaceous species beneath their canopy and induce the autogenic development of soil as "fertile islands" in the grassland ecosystems (Ren *et al*., 2008; Kondo *et al*., 2012). Indeed, woody plants can improve soil nutrients and chemical condition in their rhizosphere (Motamedi *et al*., 2018). Although in recent years, the function of nurse plant has been investigated in different habitats around the world, including grasslands (Cavieres *et al*., 2006); the effect of this nursing role on soil has been hardly compared between grazed and ungrazed areas. Previous studies showed that woody species facilitated the establishment of other plant species in the grazed areas. For instance, Smit *et al.* (2006) showed that woody species as nurse plants protect tree sampling and herbaceous seedling against large herbivores and it is supposed that grazing is a major driving force behind this facilitative process. However, the facilitative effects of woody species on understory vegetation in grazed vs. ungrazed areas have been previously discussed (e.g. Rousset and Lepar, 2000) while studies on understory soil are scarce.

Soils globally represent 75% of the total terrestrial carbon pool. Particularly, grassland soils are noted for their high levels of soil organic matter, including TC and labile fractions such as POM (Van Veen and Paul, 1981). The levels of soil C (to 20 cm depth) in grassland alone have been estimated at approximately 96 Gt (Bu *et al*., 2012). So, grassland soils are globally important for carbon sequestration, if managed properly, that can be sink of atmospheric CO_2 and the small fluctuations of TC and POM may potentially alter the atmospheric CO_2 concentration and also, the global climate (Bu *et al*., 2012). As a result, we need to evaluate soil organic matter fractions (e.g. TC and POM) in different plant communities and treatments to manage properly in which the highest level of carbon sequestration is occurred. Therefore, two main soil parameters were selected in this research, i.e. total carbon (TC) and particulate organic matter (POM). Intensive grazing by sheep and cattle has a long history in the ecotone between temperate forest and subalpine grassland in the northern Iran where unvegetated gaps have been formed by overgrazing. Therefore, the restoration of degraded sites is a concern for the managers, and needs to clarify the role of woody plants in conservation of soil against overgrazing. Briefly, the aim of this study was to investigate how a facilitative relationship between nurse plant and soil parameters would change with and without intensive grazing.

Materials and Methods

Description of the study area

This study was carried out in Vaz watershed, north of Iran. Two ecosystems are recognizable along the altitudinal gradient in the north: Hyrcanian forest in <2200 m a.s.l. and subalpine grassland, which started at 2200 m a.s.l. toward the highest elevations. The ecotone between forests and grasslands in the forest-grassland boundary in which shrub and small tree species spread in a matrix of herbaceous species, e.g. Festuca ovina L. and Brachypodium pinnatum L. (Erfanzadeh *et al.*, 2013) are recognizable. Since the ecotone is high in plant production, it has been grazed intensively by sheep and cattle. Therefore, the vegetation and soil have been degraded in some sites by intensive grazing of domestics and emerging soil gaps (Erfanzadeh *et al*., 2014a, and 2014b). According to the nearest climatological station to our study area, located in the subalpine rangelands (Baladeh city with elevation of 2014 m a.s.l.), the average annual rainfall was 394 mm and mean annual temperature was 5.5 °C (Khaleghi, 1998).

Site selection and soil sampling

In some parts of the ecotone, grazing animals were excluded by fences 10 years prior to the study (in 2006) for forage production. This exclosure created an opportunity to study some soil parameters by comparison with grazed areas. *Crataegus pseudomelanicarpa* Pojark. is the dominant woody species in the ecotone. According to the surface of grazed and ungrazed areas, 10 individual *C. pseudomelanicarpa* were randomly selected in the grazed areas and five individuals were selected in the exclosure. In order to determine spatial heterogeneity of soil parameters, soil samples were collected under the tree species (hereafter called patch) and the space between the tree species (hereafter called inter patch) using a 5 cm-diameter soil cores to a depth of 10 cm by auger in both grazed and ungrazed areas. The soil cores were divided into two depths: 0-5 cm and 5-10cm (Erfanzadeh *et al.*, 2013) and transported to the laboratory for chemical analysis.

Soil samples were collected in two different times (seasons) during maximum and minimum plant production in the spring (April) and autumn (October) 2016. In both sampling periods, the areas are being grazed, since livestock are present during April to October each year and after autumn, they are not able to go out for grazing due to climatically harsh conditions. In each patch (or inter patch), 10 soil cores were collected and created a combined soil sample for each depth.

Soil and data Analyses

Soil samples were sieved, the roots and coarse gravel (>2mm) were removed by sieving, and the <2mm soil was used to examine the effects of independent variables on soil parameters. Total organic carbon (OC) was determined by the Loss of Ignition method (Baskan *et al.*, 2016) and particulate organic matter was determined by physical fractionation (Zandi *et al.*, 2016).

The data were checked for homogeneity of variance by Levene test and normal distribution by Kolmogorov-Smirnov test. A repeated measured ANOVA in a general linear model using SPSS ver. 17 software was conducted with “season” as repeated variable, and “patch”, “depth” and “grazing” as between subject factors.

Results

The ANOVA results revealed that the main factors (season, grazing, patch and depth) and their interactions had different significant effects on the total carbon and particulate organic matter (Table 1).

Total carbon (TC)

The main effects of patch, depth and season were significant on TC (Table 1) in which TC was higher in patch (1.54%) compared with inter patch (1.47%) (Table 2) and the soil upper layer was higher (1.29%) than soil deeper layer (1.72%) (Table 2) and in the autumn, it was higher (1.57%) than the spring (1.44%) (Table 2). The season × grazing × patch interactions effect was significant for total carbon (p<0.01) (Tables 1 and 4). The total carbon was significantly higher under woody canopy (1.53%) compared with outside the canopy (1.35%) in the grazed area in the spring. While the mean of total carbon between patch and interpatch was not significant in the ungrazed area in the spring (both 1.43%).

Particulate Organic Matter (POM)

The main effects of season, grazing, patch and depth were significant for POM (Table 1) in which POM was higher in the spring (21.27 g kg^{-1}) compared with the autumn (11.80 g kg^{-1}) (Table 2) and in the grazed area, it was lower (15.04 g kg^{-1}) than ungrazed area (18.00 g kg^{-1}). In addition, the results of main effects showed that POM content was higher in patch (19.00 g kg^{-1}) than interpatch (14.04 g kg^{-1}) (Table 2) and in the upper soil layer, it was lower (13.80 g kg^{-1}) than deeper soil layer (19.24 g kg^{-1}) (Table 2). The season × patch interactions effect was significant for POM (Tables 1 and 3). In the spring, higher POM content was observed in the patch (25.22 g kg^{-1}) while in the autumn, there was no significant difference between patch and interpatch (Table 3).

Table 1. The results of ANOVA for soil parameter comparisons for the main effect of all of factors (season, grazing, patch and depth) and their two way, three way and four way interactions effects

Source	DF	Total C		POM	
		F	Sig.	F	Sig.
Season	1	45.50**	**0.00**	55.47**	**0.00**
Grazing	1	1.58	0.21	4.96*	**0.03**
Patch	1	7.15**	**0.01**	13.81**	**0.00**
Depth	1	304.6**	**0.00**	16.68**	**0.00**
Season × Grazing	1	0.68	0.41	0.07	0.79
Season × Patch	1	1.22	0.27	5.64*	**0.02**
Season × Depth	1	3.90	0.06	0.13	0.71
Grazing × Patch	1	2.91	0.09	0.70	0.40
Grazing × Depth	1	0.02	0.87	0.31	0.57
Patch × Depth	1	0.53	0.46	2.05	0.81
Season × Grazing × Patch	1	6.40**	**0.01**	0.00	0.96
Season × Grazing × Depth	1	0.86	0.35	0.92	0.34
Season × Patch × Depth	1	0.32	0.57	0.17	0.67
Grazing × Patch × Depth	1	0.00	0.93	0.06	0.80
Season × Grazing × Patch × Depth	1	0.02	0.87	0.20	0.65

**, * significant at 1% and 5% probability level, respectively.

Table 2. The main effect of season, area, woody patch and soil depth on total carbon (%) particulate organic matter (POM g kg^{-1}) in each season in grazed and ungrazed areas.

Factors	Levels	Total C (%)	POM (g Kg^{-1})
Seasons	Spring	1.44±0.04 b	21.24±3.37 a
	Autumn	1.57±0.04a	11.80±1.05 b
Area	Grazed	1.52±0.03 a	15.04±1.61 b
	Ungrazed	1.49±0.04 a	18.00±2.82 a
Woody patch	Patch	1.54±0.03 a	19.00±2.79 a
	Interpatch	1.47±0.03 b	14.04±1.63 b
Soil Depth	0-5 cm	1.72±0.03 b	13.80±1.67 b
	5-10 cm	1.29±0.05 a	19.24±3.01 a

For each factor, means of column followed by similar letters have no significant differences

Table 3. The season by woody patch interaction effect on total carbon (TC) and particulate organic matter (POM).

Season	Woody patch	TC (%)	POM (g Kg^{-1})
Spring	Patch	1.48 a	25.22 a
	Interpatch	1.39 b	17.26 b
Autumn	Patch	1.59 a	12.78 b
	Interpatch	1.55 a	10.83 b

Means of column followed by similar letters have no significant differences

Table 4. The season by area by woody patch interaction effect on total carbon (TC) and particulate organic matter (POM).

Season	Area	Woody patch	TC (%)	POM (g Kg^{-1})
Spring	Grazed	Patch	1.53 a	24.43 a
		Interpatch	1.35 b	15.41 b
	Ungrazed	Patch	1.43 a	26.00 a
		Interpatch	1.43 a	19.10 a
Autumn	Grazed	Patch	1.61 a	11.71 b
		Interpatch	1.58 a	8.59 c
	Ungrazed	Patch	1.57 a	13.84 b
		Interpatch	1.52 a	13.07 b

Means of column followed by similar letters have no significant differences

Discussion

In this study, different soil parameters showed different reactions encounter with the seasons. Total carbon was not changed along season while the particulate organic matter was drastically decreased from spring to autumn. This might reflect the fact that soil labile carbon is an active part of soil organic carbon and more sensitive to environmental factors than total organic carbon. Previous studies showed that some soil parameters were changed in different seasons. For instance, the study of Singh *et al.* (1989) in forest and grassland ecosystems showed that soil microbial biomass was high during the summers because plant growth was limited, but microbial growth could still occur under limited water conditions, thereby still immobilizing N. In addition, soil microbial biomass N (MBN) was low during the rainy season (autumn and winter) because of N uptake from soil by plants (Yu *et al.*, 2008). They suggested that temperature and plant growth were the major factors influencing soil characteristics. Wang *et al.* (2005) stated that the correlation coefficient of soil organic carbon was lower than that of soil labile carbon with precipitation. However, the lower values of particulate organic matter in autumn compared with spring, in our study, might be due to soil erosion and leaching by precipitation. We believe that accumulated precipitations in the spring and autumn washed particulate organic matter by runoff and leached into deeper depth.

Generally, the main effect of grazing on particulate organic matter was significant and decreased particulate organic matter in both seasons. Grazing is able to reduce carbon fractions by reducing litter input into the soil and soil microbial populations and retarding biological activities (Eldridge *et al.*, 2015; Daryanto *et al.*, 2013; Abdulahi *et al.*, 2016). Our results about higher particular organic matter in ungrazed areas consistent with other studies (e.g. Facelli and Temby, 2002). Rotich *et al.* (2018) reported that both rotational and continuously grazing decreased soil carbon fractions significantly (Rotich *et al.*, 2018). This research showed that the mechanism for greater nutrient concentration in ungrazed areas could be related to changes in soil bulk density through soil trampling and compaction, increased bulk density, decreased plant production and C content.

Many studies have suggested that grazing in grasslands play an important role in creating a high degree of spatial structuring and local variability in soil resources (e.g. Augustine and Frank, 2001). Franzluebbers *et al.* (2000) showed that grazing behavior could influence the spatial distribution of soil biochemical properties in pastures that have been grazed for long periods. Although, the results showed that the main effect of grazing on total carbon was not significant, but the results indicated that the three-way interaction between grazing, season and patch was significant in the spring. So, total carbon was significantly higher under the woody canopy compared with outside the canopy in the grazed area (see Tables 1 and 4). While in ungrazed area, there was no significant difference of total carbon between patch and interpatch. As a result, we conclude that woody plants saved the total carbon against animal grazing. We observed the same distribution patterns in particulate organic matter in both seasons. This soil parameter was more evenly distributed in the ungrazed area because the vegetation might form a relatively more continuous soil cover compared with grazed area (see also Ruiz *et al.*, 2008). Therefore, based on the results of this study, it can be concluded that in the ungrazed areas, the distribution of soil nutrient resources is uniform and soil resource heterogeneity between patches and interpatches is very low. Conversely, in grazed area, the differences of soil parameters between patch and interpatch were more obvious. Probably, livestock grazing resulted in a dominant perennial grass with relatively lower cover, height and biomass outside the patches. On the other hand, probably rainwater runoff accelerates the redistribution of soil resources and increases the spatial variability of C in the soil in the grazing area with a combination of low soil litter input and deforming of woody plants due to grazing. Thus, the habitat dominated by perennial grasses and healthy-intact woody species in ungrazed areas degrades into habitats consisting of reforming overgrazed woody species together with relatively poor soil. Several studies in habitats with woody plants in a matrix of grasslands showed that shade under woody species increases the understory herbaceous productivity due to the enhancement of moisture and reduces of grazing pressure (Erfanzadeh *et al.*, 2014b; Xu *et al.*, 2015).

Our study showed that soil fertility indices such as OM were significantly higher under canopy of smaller tree than in the open area. Previous studies reported that soils under woody canopies are more fertile than soils from the surrounding grasslands (e.g. Abdallah *et al.*, 2012, Noumi *et al.*, 2012; Dohn *et al.*, 2013; Noumi, 2015). The increase of C content in soil under tree canopy can be a results of the deposition of leaf litter produced by the tree itself and other herbaceous species growing under the canopy since it has been shown that woody plants are strong facilitators for grasses and forbs (Howard *et al.*, 2012), all of which are known to enhance soil carbon (Han *et al.*, 2008). Numerous studies have shown that the establishment and fecundity of herbaceous plants are higher in the shrub patch than in the surrounding areas (Badano *et al.,* 2009). Such facilitation is mainly attributed to the engineering effect of shrubs, which improves the physical, chemical and hydrological conditions for herbaceous vegetation growing in shrub patches compared with conditions in open patches (Noumi, 2015). Patches of woody vegetation can also modify plant community composition and dynamics by trapping seeds and creating suitable microhabitats (Aerts *et al.*, 2006). Therefore, these herbaceous species accompanying the shrub can increase soil organic matter.

The content of total carbon in all cases and the content of particulate organic matter in many cases were higher at the surface than in the deeper soils, agreeing with the former findings in the other ecosystems (Su *et al.*, 2004). Since adding the litter produced by aboveground vegetation and shallow roots into soil might be higher than that produced by deep roots, soil parameters were mostly transferred from the surface to the deeper soils gradually with the time going on, the soil vertical heterogeneity emerged, the highest values in the surface and the lowest values in the deepest soils (see also Wang *et al.*, 2006). However, Stock *et al.* (1999) found that soil parameters under *R. cyathiformis* and *Ruschia* sp. did not differ between the surface and the deeper soils in the arid ecosystem.

Conclusion

Woody plant species in a background of grasslands play an important role to enhance soil quality parameters, i.e. total and particulate organic matter. However, the facilitated role of woody species on conservation of soil quality parameters are more pronounced in overgrazed compared with ungrazed grasslands. In overgrazed areas, the presence of woody plant species is important to save the soil against grazing in which the rangeland manager should consider in the rangeland development and improvement projects.

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تاثیر تاج *Crataegus pseudomelanicarpa* Pojark. بر کربن کل و مواد آلی ذره‌ای خاک در دو منطقه چرا شده و چرا نشده در مراتع البرز شهرستان نور

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چکیده. درختان و گیاهان بوته‌ای به عنوان پرستار، باعث کمک به رشد و توسعه گیاهان علفی زیراشکوب خود شده و نهایتا خاک زیراشکوب را نیز تحت تاثیر قرار می‌دهند. بنابراین در این تحقیق تاثیر تاج *Crataegus pseudomelanicarpa* بر مقدار کربن خاک (بصورت کربن کل و ماده آلی ذره‌ای) در دو منطقه چراشده و چرا نشده در دامنه‌های البرز مرکزی مراتع روستای پس‌پرس شهرستان نور مطالعه گردید. بدین منظور ۱۵ پایه درخت (بر اساس وسعت هر منطقه ۵ پایه در منطقه چرانشده و ۱۰ پایه در منطقه چراشده) انتخاب شدند و نمونه‌های خاک در دو فصل بهار و پاییز سال ۱۳۹۶ از بیرون و زیر تاج‌پوشش گونه چوبی برداشت شدند. فاکتورهای کربن کل و مواد آلی ذره‌ای نمونه‌های خاک اندازه‌گیری شدند. نتایج اثرات اصلی نشان داد که کربن کل در پاییز بیشتر از بهار بود در حالیکه مواد آلی ذره‌ای در بهار بیشتر از پاییز بود. به طور کل نتایج بیانگر بهبود مقدار کربن کل و مواد آلی ذره‌ای در هر دو منطقه چرا شده و نشده با حضور *C. pseudomelanicarpa* بود. در منطقه چراشده مواد آلی ذره‌ای (۲۴/۴۳ در مقابل ۱۵/۴۱ گرم بر کیلوگرم در بهار و ۱۱/۷۱ در مقابل ۸/۵۹ گرم بر کیلوگرم در پاییز) و کربن کل (۱/۵۳ در مقابل ۱/۳۵ درصد در بهار و ۱/۶۱ در مقابل ۱/۵۸ درصد در پاییز) مقدار بیشتری در زیر تاج گونه چوبی نسبت به بیرون تاج داشتند در حالیکه در منطقه چرا نشده این تغییرات معنی‌دار نبودند. نقش پرستاری گیاهان بوته‌ای در حفظ کربن خاک در منطقه چرا شده قویتر از منطقه چرا نشده عمل می‌کند. بنابراین تاکید بر حفظ گیاهان بوته‌ای در مراتع بویژه در مناطق چرا شده می‌گردد.

کلمات کلیدی: گیاهان پرستار، ویژگیهای خاک، علفزارهای زیرآلپی