Estimation of Soil Carbon Sequestration Rate in Steppes (Case Study: Saveh Rudshur Steppes)

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Abstract. Since Renaissance, the natural ecosystems have fallen into a complete state of disarray due to the rise in the amount of carbon dioxide. Soil, the unsparing stuff, is one of the major sources of carbon storage, and plays a paramount role in the global equilibrium of carbon as well as carbon sequestration. Given that Iran is benefiting from vast steppes, the rate of carbon sequestration in them deserves attention. In order to estimate the soil carbon sequestration, the Saveh Rudshur steppes were selected and placed into three treatments: long-term exclosure, medium-term exclosure and grazing rangelands. The soil sampling was conducted at the depth of 0-30 cm under the plants and between the plants. As many as 60 soil samples on each area and 180 soil samples in total were taken. The sampled soils were dried out in the open air and sifted through a sieve of 2mm meshes in the laboratory. The soil organic carbon was measured using the Walkley-Black method. The findings indicated that there was a significant difference between the amount of the soil organic carbon under the plants and the carbon between the plants on each area separately ($P<0.05$). The results also showed that the amount of organic carbon under the plants is greater than that between them in the treated exclosures while the grazing areas proved a different result. It can be seen from the mean of the total carbon sequestration that there is also a statistically significant difference between the medium-term exclosure with a mean of 22.45 ton/ha and the long-term exclosure with a mean of 17.76 ton/ha and the grazing rangelands with a mean of 18.50 ton/ha.

Key words: Soil organic carbon, Carbon sequestration, Steppes, Exclosure, Saveh Rudshur.

Introduction

The earth's surface has undergone transformations due to many organic and inorganic phenomena since the earth existence. But the fact is that the intelligent human has dominated the nature by means of instruments, techniques as well as technology, turned to be the conqueror of the earth and to be able to mark the emergence of Renaissance in the mid 18^{th} century. Today, we can refer to the climate change and the global warming as the consequences caused by Renaissance considered being the significant challenges in sustained development (Amiraslani, 2003). Many researchers maintain that the climate changes and the global warming are generated by the density in the greenhouse gases found in the atmosphere of the Earth (Brooks, 1998); and carbon is one of the major causes of the greenhouse gases (Lal, 2004). The dangers and consequences resulting from the increase in the density of the greenhouse gases, especially carbon dioxide have been the focus of international communities' attention so that in 1992, nearly all the countries in the world signed the Convention for the Climate Change in order to decrease and offset the density in the greenhouse gases. Then, in 1997, the Tokyo Protocol was approved by 55 nations to prevent the greenhouse gas leaks in long term Mahmodi, *et al.* (2007). It is obvious that the industrialized countries followed by other nations have been seeking the methods compatible with the environment and productive of fewer pollutants to reduce the air-polluting gases, especially carbon dioxide. The carbon dioxide in the nature cycle is 200 billion tons Mahmodi, *et al.* (2007) which is stored in five sources: oceans, depths of earth, atmosphere, organic resources, and soil. One method that has been proposed to decrease the amounts of carbon dioxide and to increase those of the stored carbon round the globe is to sequestrate it in the soils considering that 75% of carbon being specific to the land ecosystems is stored in the soil (Mahmodi, *et al.* 2007). Lal (2004) also viewed the world soils forming the tertiary main storage capacity of carbon (organic and mineral) and nearly 4 times of the carbon in biomass as well as 3.3 times of the amounts of carbon in the atmosphere. In a study of pasture lands within the period of 33 years, Snorrason *et al.* (2002) reported that the degree of carbon sequestration is 157 ton/ha adding that the bulk of sequestration was carried out in the soil. Furthermore, Schuman *et al.* (1999) investigated the effect of heavy and light grazing and exclosure on the US grasslands during 12 years and indicated that the carbon sequestration of soils on the grazed rangelands was greater than the enclosed areas due to the cattle strays, cattle trampling on the plant stalks and litters, as well as the crush of plants and plant jumble with the topsoil. Derner *et al.* (1997) compared the grazed ranges with the enclosed areas at two depths of 0-15 and 15-30 centimeters in terms of the rate of carbon sequestration and concluded that the carbon sequestration at the depth of 0-15 centimeters on the grazed areas was greater than the enclosed areas, but there was no significant difference at the depth of 15-30 centimeters. In an investigation of management and restoration practices of the grazing lands such as manuring and grazing in the US, Schuman *et al.* (2002) discovered that such practices gave rise to the soil carbon sequestration. Exploring the effect of distances between plants on the rate of carbon sequestration of soil in Hydrology growing in the South of Salt Lake, Ahmadi *et al.* (2009) found out that the greatest amount of sequestrated carbon occurred under the plant canopy cover and the smallest amount of sequestrated carbon in the areas devoid of any litters. Comparing the quality of litters and their effect on soil sites of three types of rangelands in the given region, Jafari *et al.* (2008) concluded that the soil-fertilizing elements (carbon, nitrogen, phosphor, etc) increased under the investigated species compared to the control areas. The findings of studies represent the significance of soils as one of the most important stores of carbon and the impact of management practices on the rate of carbon sequestration. In Iran, the rangelands as a land ecosystem have covered a vast area of the country so that the steppes constituting %47 of the entire rangelands of the country is of great importance (Mesdaghi, 2004). The soils in the steppes are recognized as one of the most essential elements in the ecosystem and should be explored from a variety of aspects including carbon sequestration. The reason is that soils form the third large stores of carbon in the world (Lal, 2004). Moreover, in resources, the value of rangelands has been calculated as 50 to 300 dollars per hectare related to carbon sequestration Luciuk *et al.* (2000). Thus, the present study sets out to examine the comparison between the enclosed rangelands (long-term exclosure and medium-term exclosure) and the grazing areas as the control site in the steppes of Rudshur Saveh Yong *et al.* (2003) to measure the rate of soil carbon sequestration and to estimate its economical aspect in the given steppes so that it can, on the one hand, gauge the effect of management practices (exclosure) on the rate of soil carbon sequestration and, on the other hand, suggest an index to be used to determine the performance and potentiality of the rangelands in sustained development.

Materials and Methods

Characteristics of the region under study

The Rudshur Saveh exclosure is located in the south of RobatKarim, 60km away from Tehran in Tehran-Saveh Roadway. The average annual rainfall reported by the Aminabad Weather Station has been approximately 206.4mm during the period of 35 years (1969-2004). This region lies 1100m above sea level. The exclosure is on a longitude of 50° plus 53 mins and latitude of 35° plus 26 mins. It consists of two parts in length of time: the long-term exclosure (30 hectares in area since 1965) and medium-term exclosure (20 hectares in area since 1985). The dominant species in the exclosures include *Stipa hohenackeriana* Trin. And Ruper. Salsola tomentosa (Moq) Spach in Kotschy, *Artemisia sieberi* Besser. Furthermore, *Artemisia sieberi* Besser lies in the outer areas of the exclosure which is the main species.

Materials and Methods

The aforementioned areas were divided into three sites: long-term exclosure, medium-term exclosure and grazing areas. All the three areas were flanked on a steep gradient with parallel sides. The soil sampling was conducted randomly on each site. The sampled soils were carried out at the depth of 30 cm in two ways: under plants and between plants (i.e., where the soils were plant-free). Gao *et al.* (2007) argued that the changes in the soil organic carbon in the depths greater than 30 cm are quite small. 60 soil samples on each area (e.g. 30 samples under the plants and 30 samples between the plants due to the area width as well as the appropriate dispersal of the samples), and 180 soil samples in total were drawn out and moved to the laboratory. They were dried out in the open air and sifted through a sieve of 2mm meshes. The soil organic carbon was measured using the Walkley-Black method, and to estimate the percentage of total carbon, the bulk density of the soil samples was obtained by clog. Regarding the goal of study, the mineral layer thickness, carbon accumulation and bulk density of soil were specified as the variables. In order to determine the amount of the sequestrated carbon by the gram per meter square, the formula 1 was employed: Formula 1 (22) Cc = 1000×C (%) ×Bd×e, in this formula, **Cc** refers to the amount of the sequestrated carbon weight per meter square. **C** signifies the percentage of the accumulated carbon in the calculated depth of soil. **Bd** represents the bulk density of the soil, and **e** denotes the thickness of the soil depth by the centimeter. The gathered data were processed using Excel software 2003, and their analyses were performed on the SPSS Version 12. A paired-samples t-test was used to compare the rate of soil carbon sequestration under the plants with those between the plants. A One-way ANOVA was utilized to examine the effect of exclosure and grazing on the rate of carbon sequestration, and a Duncan Test was applied to compare the mean of carbon sequestration on the three areas.

Results

1. Estimation of carbon sequestration rate per level

The results obtained from the estimation of the amount of sequestrated carbon per level (meter square and hectare) on each area are shown in Table 1. Thus, the amount of the sequestrated carbon was 17.76 ton/ha in the long-term exclosure, 22.45 ton/ha in the medium-term exclosure, and 18.50 ton/ha in the grazing areas.

Table 1. The Mean of Carbon Sequestration Rate (ton/ha) on Long-term, Medium-term xclosure and Grazing Areas (Soil depth 30 cm)

Sampling location	Exclosure time	Carbon dispersion (c) %	Physical specific weight (Bd) gr/cm^3	Carbon Sequestration (Cc) Kg/m^2	Carbon Sequestration ton/ha
Under Plants	Long-term	0.532	1.355	2.116	21.62
	Medium-term	0.606	1.332	2.421	24.21
	Grazing Areas	0.367	1.405	2.421	15.47
Between Plants	Long-term	0.339	1.413	1.437	14.37
	Medium-term	0.549	1.361	2.070	20.70
	Grazing Areas	0.447	1.606	2.153	21.53
Mean	Long-term	0.44	1.38	1.78	17.76
	Medium-term	0.58	1.35	2.25	22.45
	Grazing Areas	0.41	1.51	2.29	18.50

2. Comparison of carbon sequestration Rate under Plants with those between plants on each area

The results obtained from the statistical analyses indicate the difference at 90% level between the characteristics investigated in all the three areas. The comparison of sequestrated carbon rate under plants with the carbon between plants in all sites is also shown in (Table 2). As we can see, the results obtained from the paired-samples t-test indicate that there is a significant difference between the carbon under plant species and the stored carbon between plants (P<0.05).

Table 2. Comparison of carbon sequestration rate in the soils of 3 sites: long-term exclosure, medium-term exclosure, grazing areas for under plants a between plants based on paired-samples t-test.

Areas under study	Sampled elements	Number of samples	T test	Standard error ± Mean
Long-term Exclosure	Under plants	10	2.27*	21.62 ± 5.48
	Between Plants	10		14.37 ± 6.11
Medium-term Exclosure	Under plants	10	2.48*	24.21 ± 5.55
	Between Plants	10		20.70 ± 3.35
Grazing Areas	Under plants	10	2.27*	15.47 ± 6.45
	Between Plants	10		21.53 ± 3.84

The asterisk (*) shows the significance at P level (P< 0.05).

3. Comparison of carbon sequestration rate in the soils Under plants and between plants in 3 areas

The results obtained from the comparison of carbon sequestration rate in the soils under plants and between plants in three areas based on the ANOVAs and Duncan Test show the differences in the amount of the sequestrated carbon (Table 3) to the extent that there was a significant difference between the amount of the stored carbon in the soils under plants on the exclosures and grazing areas and the amount of the stored carbon between plants of the long-term exclosure (Table4).

4. Comparison of total amounts of sequestrated carbon in 3 areas

The results obtained from the examination of total amounts of the stored carbon in three sites, i.e. long-term exclosure, medium-term exclosure and grazing rangelands show that the rate of carbon sequestration on the medium-term exclosure was greater than the long-term exclosure and the grazing areas and differed significantly at P level ($P< 0.05$) (Table 3) so that the Duncan Test could separate the two groups. Therefore, the long-term exclosure and the grazing areas fell into the primary group and the medium-term exclosure into the second group (Table 4).

Table 3. Results of ANOVAs on the Amount of the Sequestrated Carbon under Plants and between Plants on 3 Areas

Sources of Variation	df	MS under Plants	MS between Plants	df	MS Total Amounts of Carbon
Between Groups	2	201.55*	153.37*	2	119.62*
Within Groups	27	34.21	21.18	57	35.157

The asterisk (*) shows the significance at *P* level ($P< 0.05$).

Table 4. Results of Duncan Test on the Amount of the Sequestrated Carbon on 3 Areas

Survey Areas	Plant Feet Soils	Plant Inter-distance Soils	Total Amounts of Carbon
Long-term Exclosure	21.62 a	14.37 a	17.67 a
Medium-term Exclosure	24.21 a	24.21 b	22.45 b
Grazing Areas	15.47 b	21.53 b	18.50 a

The heterogonous letters show the differences at P level ($P< 0.05$).

Conclusion and Discussion

The estimation of sequestrated carbon rate and the obtained results showed that the total amounts of the stored carbon under different treatments as well as soils of under plants and between plants bear differences. The reason for the very differences is the plant species which had an enormous influence on the carbon sequestration in each area. The increase in the amount of carbon under the canopy covers compared to the areas with no covers can be seen as arising from the above ground of such plants on the ground and the heightened levels of biological practices in the living organisms as well as the vascular movement of surplus elements into the plants and roots into the soil. These results agree with the findings reported by Ja'fari *et al.* (2008). Moreover, similar results were observed in the general comparison of the soils under plants and those between plants in three areas. Ahmadi *et al.* (2009) also reported similar results. The rate of carbon sequestration on the rangelands, distant from the plant bushes and the plant-free areas, were greater than the canopy cover. The reasons are that there was a small size of vegetations above ground and litters were moved by the cattle to the areas away from the plants, the soil was washed out as a result of erosions helping the materials move to other areas, so that the obtained results correspond to what Schuman *et al.* (1999) reported as well. The findings from the general comparison of the investigated sites indicate that there is a statistically significant difference in the rate of carbon sequestration between the two long-term and medium-term exclosures. But this difference between the long-term exclosure and the grazing areas is not observable. To put it another way, the long-term exclosure with the mean of total stored carbon (i.e. 17.76 ton/ha) along with the grazing rangelands with the mean of 18.50 ton/ha fall into one group while the medium-term exclosure with the mean of total stored carbon (i.e. 22.45 ton/ha) stands as a separate group. These results show that the management practices had impact on the amount of carbon storage (there is not of course such a thing in the long-term exclosure due to the extraneous factors). Similarly, the results reported by Schuman *et al.* (2002) indicated that the kinds of management practices have impact on the rate of carbon sequestration. The drop in the carbon storage on the long-term exclosure can be referred to the elongation of the exclosure time. Because of 45 years of enclosing the region and preventing the cattle's entrance, the vertebrates and invertebrates (such as rabbits and ants) have reduced their activities to a considerable degree, hence resulting in the deaths, the decreasing number of the plant varieties, especially artemis sieberi as the dominant species of the site, and the emergence of the one-year-old grass-like broad-leaved plants (Mahdavi, *et al.*, 2007). Yang Zhung Sue *et al.* (2003) also reported that if the vegetations are destroyed, the litters decrease in number and the soils become defertilized, then the amount of carbon in the plan-soil system will definitely drop. The rate of carbon sequestration on the medium-term exclosure rose to the maximum. After 25 years, this exclosure, however, has benefited from the greatest varieties of plant species, the highest number of canopy covers and the lowest death rate of plants, the highest number of litters and finally, the reduction in the number of plant-free areas (the bare soils) (Mahdavi, *et al.*, 2007). Furthermore, the difference between the mean of the sequestrated carbon under the plant species in the plant-free area of the site was smaller than the other two areas. The reasons for that can be those aforementioned. There was also an approximately average rate of carbon sequestration in the selection of the rangelands as the control area and the selection of the representative area therein, regarding the existing grazing conditions. Therefore, we can conclude that the systematic management and the appropriate grazing circumstances can bring about the longevity of site and the increasing rate of carbon sequestration while many studies confirmed that grazing to a reasonable and light degree would instigate the escalating rate of carbon sequestration (Abdi, *et al.* 2007; Derner, and Schuman, 2007; Yong, and Tong, 2003). The current management of the enclosed rangelands (long-term) helped endanger its robustness Mahdavi *et al.* (2007) which is in contrast with the systematic management capable of guaranteeing the maintenance of the ranges. In the modern approaches to management, the stocking rate of carbon is considered to be an index of productivity of the rangelands, in spite of logical utilization of the plant species. With reference to the least value of carbon sequestration (i.e. \$50 per ton) (Luciuk, *et al.*, 2000) and the carbon sequestration with an average of 18 ton/ha on this site, it can be argued that the value of carbon sequestration per hectare will be equal to \$900.Considering the 46 million hectares of the steppes in Iran, it will amount to \$41 billions. Now, if we compare the value of the carbon sequestration of steppes worth \$41 billion (41×10^{11} R) with the value of the produced forage of the grasslands all over Iran worth \$$16.05\times10^{8}$ (16050 billion Rials), we will gain the economic appreciation of the carbon sequestration. Therefore, the management of rangelands should be directed to allow for their ecologic performance and capacity considering the environmental economy of rangelands so that in broad terms, the justification for the enhancement and maintenance of the economic equilibrium can be viewed as a guaranty of implementing the range managements resulting in sustained development.

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