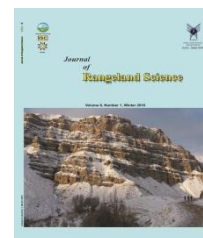


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Research and Full Length Article:

Potential of Carbon Sequestration of *Hammada salicornica* Vegetation Type in Desert Areas (Case Study: South Khorasan, Iran)

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Abstract. Climate change due to increasing the level of greenhouse gases including CO₂ is the main environmental issue of the world in the new century. One of the effective way for reducing atmospheric CO₂ is carbon sequestration by plants and soils. A vast area of Iran has desert condition with special adapted plant species in which can be devoted for carbon sequestration. *Hammada salicornica* as a shrub plant of chenopodiaceae grows as dominant or key species of vegetation types in many parts of desert areas in south of country. So, potentials of carbon sequestration of *H. salicornica* vegetation types were estimated in seven sites in South Khorasan province, Iran. For this purpose, 113 individual plants were measured for height, and long and short diameters of plant crown area and then were cut from ground level. To estimate underground biomass, roots of 10 individual plants were pulled from soil by digging the root zone. Dry matter production of shoots and roots were weighted and some samples were burned for determination of organic carbon. Organic carbon of soil of three sites were measured by soil sampling. Results showed that carbon has been sequestered between 133 to 3293 kg/ha in different sites in which James and Sefarsakh had the highest and the lowest amount of organic carbon in plant vegetation parts. Soil organic carbon obtained about 6313 kg/ha on average. The best linear regression equation ($R^2=0.90$) for estimating aerial biomass of *H. salicornica* obtained by using crown area in the equation. It seems that conservation of natural vegetation of *H. salicornica* and or restoration of degraded lands by this plant, have good potentials for carbon sequestration for globally action commitment and providing benefits such as forage and fuel for local people.

Key words: Climate change, *Hammada salicornica*, Desert areas, Carbon sequestration, Regression equation

Introduction

Greenhouse gases emission to the atmosphere especially CO₂ is one of the main causes of climate change and global warming. Fossil fuel burning and land vegetation degradation by development of annual cultivated crops, overgrazing, range and forest clearing are the main causes of oxidation of organic carbon to CO₂. It has been forecasted that phenomena of climate change will cause changes in air and soil temperature, water stored in the soil and its nutrients, changes in natural ecosystem such as water availability and biodiversity at the regional and global scale particularly in arid and semiarid regions (IPCC, 2007; Lund, 2007; Lal, 2008; Zhang *et al.*, 2012). This problem enforced the governments to signed international convention on climate change mitigation and the reduction of greenhouse gases. Generally, increasing the amount of accumulated carbon by establishing the sinks by carbon sequestration, preventing the emission of carbon from the sinks to the atmosphere by carbon conservation and reducing the demand for fossil energy by other forms of energy as carbon substitution accounted as effective ways for climate change mitigation (IPCC, 2007 and Lal, 2008). In this regards, plants and soils accounted as efficient CO₂ collectors through changing the cultivation systems from annual to perennial plants, using fertilizing for improvement of plant growth, restoration of degraded land vegetations and selecting species with good yield and root production (Anderson and Coleman, 1985; Ayoub and Malcolm, 1993; Datjes, 1998; Werwij and Emmer, 1998; Guo and Gifford, 2002; Lal, 2004).

Afforestation and conversion of marginal lands to carbon sequestration are another options in which recommended by Kuliev (1996), Luciuk *et al.* (1999) and Lee and Dodson (1996). Derner and Schuman (2007), Booker *et al.* (2012) and Naseri *et al.* (2014) stated

that rangelands ecosystems may have great potential on carbon sequestration. Desert areas comprise considerable area of the country (19.6%) with different plant vegetations and seems to have great potential for carbon sequestration, but these areas encountered with many threats like land use change, disturbances, overgrazing, decreasing biodiversity, soil erosion and may gradually loss of organic carbon stocks (Forest, Range and Watershed Management Organization, 2004). The main aim of this study was to find another way for contributing carbon sequestration. However more fuel and forage will be provided for local people and also wind erosion will be reduced by improving and conservation of land vegetation through carbon sequestration. So, to test this idea, this potential of desert areas has been evaluated as a case study in areas with *Hammada saliconica* vegetation types in South Khorasan province.

Materials and Methods

This study carried out in South Khorasan province of Iran (Fig. 1). Study area is located in the south of this province between 31° 55' 55" to 33° 57' 49" of N latitude and 56° 16' 06" to 60° 06' 49" of E longitude. This region has arid and desert climatic condition with mean annual rainfall of 110 mm. Soils are sandy from windy sand deposits to sandy gravel in different sites as has been described in Table 1.

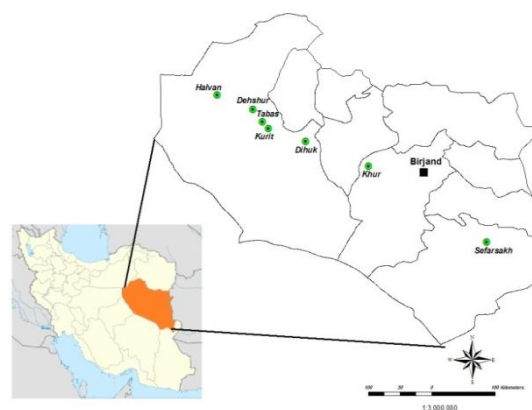


Fig. 1. Situation of study area in South Khorasan province and Iran map

Table 1. Mean annual precipitation and soil characteristics of study area

Sites	Rainfall (mm)	Soil Characteristics
James	83	sandy loam, mainly windy sand deposit, soil depth 50 cm
Dehshur	83	sandy with gravel composition, soil depth 40 cm
Halvan	83	sandy, mainly sand dune, soil depth 45 cm
Kurit	83	Sandy with gravel composition, soil depth 40 cm
Daihuk	110	Sandy, soil depth 30 cm
Khur	103	Sandy loam with little clay, soil depth 30 cm
Sefarsakh	105	Sandy loam with little clay, soil depth 35 cm

Hammada salicornica is a leafless, succulent dwarf shrub plant species with maximum 180 cm height, belong to Chenopodiaceae family and observed as a dominant or key species of natural vegetation types in many parts of this area. Other important companion species were *Haloxylon ammodendron*, *Artemisia sieberi*, *Picornocycla spinosa*, *Cornulaca sp.*, *Anabasis sp.*, *Cymbopogon olivieri*, *Astragalus squarrosus*, *Pteropyrum aucheri* and *Fourtuenia bungei* in which varied among sites.

In this study, 113 individual plants of *H. salicornica* from seven natural vegetation sites including 24 plants from Jems, 17 plants from Dehshur, 16 plants of each sites of Halvan and Kurit and 10 plants of Daihuk of Tabas region, 20 plants from Khur of Birjand and 10 plants from Sefarsakh of Nehbandan, were cut in ground level after being measured by height, and long and short diameters of plant crown in situ. The above ground material of *H. salicornica* separated into annual growth production as forage proportion, and the rest aerial material including brunches and stems accounted as woody material production.

Root biomass of *H. salicornica* measured by digging the root zone of 10 individual plants and pulled the root from the soil. The mean dry matter of roots of individual plants was used for estimation of root biomass by using the root to shoot biomass coefficient.

All amount of shoot and root biomass of each plant air dried to constant weight for about 10 days and then weighted for determination of dry matter production per plant. Total biomass of individual plant of *H. salicornica* calculated by

adding the amount of the above and below ground biomass. Number of individual plants of *H. salicornica* were counted by using five quadrates of 50 × 2 m in each site and used for calculation of plant biomass per hectare.

Contribution of biomass of companion perennial plant species in *Hammada salicornica* vegetation types accounted by cutting them into ground level and considered as above ground biomass of companion species. Proportion of the root production of these species were also determined by measurement the root biomass of some companion species for providing coefficient for calculating below ground biomass. Both of above and below ground biomass of companion species considered as total biomass of companion species. The total biomass of plant part skeleton per hectare in each vegetation site calculated by adding biomass of *H. salicornica* and companion species.

Some samples of dry matter of *H. salicornica* and companion species taken to the laboratory and put into a furnace with 450°C for three hours. The amount of organic carbon calculated by following Equations 1 and 2 (Jana *et al.*, 2009):

$$OM\% = [(DM - AW)/DM] \times 100$$

$$OC\% = (OM/1.724) \times 100$$

(Equations 1 and 2)

Where

OM= organic matter,

DM= dry weight of sample,

OC= organic carbon

AW= ash weight of the sample.

Soil samples from three sites of Jams, Dehshur and Kurit were collected from depth of 0-30 cm and then taken to the soil laboratory. Soil Organic Carbon

(SOC) measured by conventional method.

Data of aerial biomass of individual plant of *H. salicornica* in different sites were examined by analysis of variance using the General Linear Model (GLM) procedure of SAS (SAS institute 1991) and means by Duncan's test. The mean production of dry matter biomass and organic carbon of each parameter have been compared for different sites.

Relationship between aerial biomass production of *H. salicornica* as dependent variable and height, short

diameters, long diameters and crown area, as independent variables were used for estimating above ground biomass through linear regression analysis.

Results

Plant biomass and organic carbon content

Aboveground biomass of individual plant of *H. salicornica* varied significantly ($P < 0.01$) among sites. The highest and the lowest plant biomass obtained from harvested individual plants in James and Sefarsakh respectively (Table 2).

Table 2. Comparison between individual plant biomass of *H. salicornica* in different sites

Sites	Plant Biomass (kg)	Standard Deviation
James	9.986 a	9.539
Dehshur	2.548 bc	3.416
Halvan	2.761 bc	1.968
Kurit	4.429 b	2.126
Daihuk	3.404 bc	2.980
Khur	0.568 bc	0.675
Sefarsakh	0.038 c	0.216

Means of plant biomass followed by the same letters has no significant differences based on Duncan method

All results of dry matter production (DM) and Organic Carbon (OC) of *H. salicornica* and other companion species in different sites have been shown in Table 3. There were differences between sites for all measured parameters. In this regard, amount of annual dry matter production of *H. salicornica* ranged from 67 to 1162 kg/ha and for the woody dry matter production from 64 to 1480 kg/ha among sites. The mean above ground biomass of *H. salicornica* of different sites obtained about 888 kg/ha.

The root to shoot weight ratio of remth obtained about 0.38. So, based on calculated coefficient, root biomass of *H. salicornica* estimated between 56 to 1003 kg/ha in different sites. Total plant biomass of *H. salicornica* obtained about 1226 kg/ha on average in which site of James had the highest (3645 kg/ha) and Sefarsakh the lowest (202 kg/ha) amount of plant biomass.

The above ground biomass of companion species were also differ among sites, from 28 kg/ha in Khur to 2510 kg/ha in James. The mean root to

shoot ratio of about 0.21 calculated for companion species. Therefore, total biomass of companion species obtained between 34 to 3037 kg/ha in the measured sites.

In general, total biomass of plant vegetation were different between sites and ranged from 269 to 6682 kg/ha. The mean proportion of *H. salicornica* from total biomass became about 69 percent.

By converting dry matter into organic matter and then organic carbon, minimum, maximum and mean weight of total organic carbon of plant vegetation became about 133, 3294 and 876 kg/ha respectively (Table 3). The site of Jems showed the highest plant biomass and the site of Sefarsakh the lowest plant biomass and consequently organic carbon stocks among the measured sites.

Table 3. Dry matter production (kg/ha) of *Hammada salicornica* vegetation types in different sites

Sites	<i>H. salicornica</i>		<i>H. salicornica</i>			Companion Species			Plant and Soil		
	Annual DM production	Woody DM production	Aerial biomass	Root biomass	Total biomass	Aerial biomass	Root biomass	Total biomass	Total plant biomass	Total plant OC	Soil OC
James	1162	1480	2642	1003	3645	2510	527	3037	6682	3294	11008
Dehshur	335	341	676	257	933	135	28	163	1096	540	4208
Halvan	423	377	800	304	1104	112	24	136	1240	611	-
Kurit	451	570	1021	388	1409	235	49	284	1693	835	3722
Daihuk	341	407	748	284	1032	112	24	136	1168	576	-
Khur	92	93	185	70	255	28	6.0	34	289	142	-
Sefarsakh	67	64	146	56	202	55	12	67	269	133	-
Mean	410	476	888	337	1226	455	96	551	1777	876	6313

Soil organic carbon content

Soil organic carbon percentage of three sites of Jams, Dehshur and Kurit obtained about 0.26%, 0.1%, and 0.07% respectively. Soil organic carbon of these sites is shown in Table 3. The amount of soil organic carbon of these sites were differ with the highest in James and the lowest in Kurit.

Biomass estimation

Plant sizes ranged from 1.35 to 0.2 m in height, 3.3 to 0.1 m in short diameter, 3.5 to 0.2 m in long diameter and 14.17 to

0.011 m² in crown area. Different results have obtained when Y considered as aerial biomass production of *H. salicornica* as dependent variable and each of height, short diameter, long diameter and crown area parameters as independent variables (X) as shown in Table 4. The best equation for estimation of above ground biomass of *H. salicornica* with higher R² value obtained by using data of crown area in the equation.

Table 4. Different equations produced using independent variables as height, short diameters, long diameters and crown area for estimation of aerial biomass production of *Hammada salicornica*

Equations (Y= Biomass)	Independent Variables (X)	R ² Values
Y = 13.806 X-6.22	Height	0.38
Y = 6.80 X- 4.73	Short diameters	0.74
Y = 5.98 X- 4.88	Long diameters	0.72
Y = 2.46 X-0.85	Crown area	0.90

Discussion

There were significant differences between sites in terms of plant size and biomass of individual plant of *H. salicornica*, and biomass production and organic carbon content of vegetation and soil. In previous study about habitat condition of *H. salicornica*, Tavakoli *et al.* (2005) mentioned that this plant mainly grows over sandy to windy soil deposits and also easily established over sand dune and forms neka. So, it seems that the differences in dry matter harvested between sites were mainly due to differences in soil textures and soil depths as has been shown in Table 1. It means that lighter soil texture and deeper soil depth, resulted in bigger plant size and higher biomass production

comparing to heavier soils and with shallower depth. For example in site of James soil was relatively deep (50 cm) with sandy to windy sand deposit texture, but in site of Khur and Sefarsakh, soil texture was sandy loam with depth of about 30 cm and gravel texture nearly below this depth.

Most of carbon stocks (88%) have been stored in soil comparing in plant parts (Table 3). These findings supported by other reports about the contribution of soil in the lands measured for carbon sequestration (Dianati Tilaki *et al.*, 2010; Naseri *et al.*, 2014). But the amount of carbon stocks in desert areas such as present study are much lower than semi-arid condition (Abdi *et al.*, 2008, Dianati Tilaki *et al.*, 2010; Gholami *et al.*, 2012;

Naseri *et al.*, 2014). Derner and Schuman (2007), Gheitury (2012) and Chang *et al.* (2014) stated that potential of carbon sequestration depend on climatic conditions, type of plant biomass, reclamation practices, physical and biological conditions of the soil and initial carbon stocks in the soil.

There are some comments that for effective carbon sequestration in which organic matter should be lasted for at least 100 years (Glenn *et al.*, 1993; Niskanen *et al.*, 1996). However, forests conservation and forestry are the best obvious example for carbon sequestration. But it seems that arid areas including desert areas have also good potential for carbon sequestration (Booker *et al.*, 2012) for different reasons: Firstly, desert areas have many perennial plants for carbon sequestration. For example in our study, physiological life of *H. salicornica* is between 15-20 years. Because this species regenerates by seeds in natural habitats or rejuvenated by sprouting after being cut from ground level (Tavakoli *et al.*, 2005).

Therefore, the natural vegetation can last permanently under proper vegetation management. Secondly, because soil water content is often low in desert areas, so, in this situation the activity of soil organisms and consequently degradation of organic matter is also relatively low and it would be expected that organic matter lasted for longer time comparing to wet areas. In addition, soils in arid areas such as soils of study area (Table 3) have low organic carbon and, therefore would have more sink capacity for dry matter accumulation. Thirdly, in this study with about 110 mm of rainfall, *H. salicornica* vegetation types sequestered about 7189 kg/ha organic carbon in both plant skeleton and soil on average.

Because of there is a vast areas of desert rangelands in which have such as this condition in the county, therefore huge amount of carbon has been sequestered in desert areas at present

condition and or may increase by proper management.

At present time, saksaul (*Haloxylon spp.*) mainly planted for restoring degraded lands in desert areas of the country. But *H. salicornica* from the same family and much similarity to saksaul has also more drought tolerant and grows well on warmer areas with rainfall between 60 to maximum 300 mm per year. So, this species suggested to use for carbon sequestration projects in warmer areas in south of country.

Pot planting is a suitable method for restoring desert lands with *H. salicornica* (Tavakoli *et al.*, 2005). This species can be planted and managed similar to saksaul. For plantation development of *H. salicornica*, it is needed to grow it first in pots in the nursery and after a year, seedling transplanted to the farm. It should be irrigated by two to three times for the first and even the second year for good establishment and developing deep rooting system. The reclaimed lands should be excluded from grazing for three years. Beacause about half of aerial material of *H. salicornica* is as annual forage (Table 3). So it can also be used for animal grazing. Our experiences indicated that light to moderate grazing or browsing in winter time would be suitable for improving plant vitality and increasing its longevity.

Local people benefit of plant vegetation through controlling wind erosion, improving their socio-economic condition by preparing forage for their animals and also fuel for energy. Therefore, restoration and conservation of natural vegetation can be done by local people by raising public awareness, training and providing them with financial resources. As an experience, a successful carbon sequestration project has been implemented in 2003 by planting mainly *Haloxylon spp.* in the

Hossein Abad plain of South Khorasan with participation of local people. Such as this project can be practiced planting *H. salicornica* in warmer areas. In overall, the results of this action contribute carbon sequestration for climate change mitigation.

Indirectly estimation of above ground biomass of *H. salicornica* without any destruction, would allow estimating aerial biomass of *H. salicornica* by measuring of long and short diameters of plant in shorter time and with lower cost. The usefulness of this estimation would be for economic evaluation of sites and or making decision for restoration action. Such as this work have been done by many workers e.g., by Rittenhouse and Sneva (1977) for big sagebrush, and by Tajali (2012) for *Atriplex canescens*.

In conclusion, *H. salicornica* shows a good potential for carbon sequestration to be managed as natural vegetation types or used as selected species for restoration of degraded lands in desert areas. Undoubtedly, the carbon sequestration potential of natural vegetations and degraded desert rangelands will be affected and improved by restoration and proper management.

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ظرفیت ترسیب کربن تیپ گیاهی *Hammada salicornica* در مناطق بیابانی (مطالعه موردی: خراسان جنوبی، ایران)

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چکیده. تغییر اقلیم کره زمین ناشی از افزایش انتشار سطح گازهای گلخانه‌ای از جمله دی اکسید کربن چالش مهم قرن جدید است. ترسیب کربن توسط گیاهان و خاک یکی از راه‌های مدیریت انتشار کربن به اتمسفر می‌باشد. در ایران عرصه‌های وسیعی به صورت بیابان وجود دارد که دارای گونه‌های مناسب و سازگاری برای ترسیب کربن است. از این میان رمس یا ترات (*Hammada salicornica*) گونه‌ای درختچه‌ای از خانواده اسفناجیان است که در بخش‌های وسیعی از رویشگاه‌های طبیعی جنوب ایران به عنوان گونه غالب یا کلیدی در تیپ‌های گیاهی حضور دارد. در این مطالعه ظرفیت ترسیب کربن تیپ رمس در هفت منطقه در خراسان جنوبی بررسی گردید. برای این منظور ارتفاع و دو قطر کوچک و بزرگ ۱۱۳ بوته رمس اندازه‌گیری و سپس از سطح خاک قطع و پس از خشک کردن، زیتوده گیاهی بالای سطح خاک آن اندازه‌گیری گردید. برای داشتن تخمینی از زیتوده زمینی، ریشه ۱۰ بوته از خاک خارج و وزن خشک آن هم اندازه‌گیری و به عنوان نسبتی از زیتوده هوایی استفاده گردید. میزان تولید سایر گونه‌های چند ساله همراه هم اندازه‌گیری شد. میزان کربن آلی با قرار دادن مواد گیاهی در کوره و سوزاندن آنها بدست آمد. مواد آلی و سپس کربن آلی خاک هم در سه منطقه اندازه‌گیری گردید. نتایج حاصله میزان کربن آلی مناطق مختلف را متفاوت و بین ۱۳۳ تا ۳۲۹۳ کیلوگرم در هکتار نشان داد که از این میان منطقه سه فرسخ کمترین و منطقه جمز بیشترین مقدار کربن آلی را در اندام‌های گیاهی ترسیب کرده بودند. خاک سه منطقه هم دارای مقادیری متفاوتی از کربن آلی ذخیره‌ای بود و در مجموع مقدار کربن ترسیب شده در خاک حدود ۶۳۱۳ کیلوگرم در هکتار بدست آمد. در این مطالعه برای تخمین زیتوده هوایی رمس به عنوان متغیر وابسته، داده‌های ارتفاع، قطر بزرگ و کوچک و سطح تاج پوشش گیاه به عنوان متغیرهای مستقل در قالب رگرسیون خطی آزمون و نهایتاً بهترین معادله با استفاده از سطح تاج پوشش گیاه در معادله بدست آمد ($R^2 = 0.92$). در مجموع حفاظت از رویشگاه‌های طبیعی رمس و یا احیاء عرصه‌های تخریب شده با کشت رمس ظرفیت خوبی را از منظر ترسیب کربن برای تعهدات جهانی و تولید منافع متعدد نظیر تولید علوفه و هیزم برای ساکنین محلی نشان می‌دهد.

کلمات کلیدی: تغییرات اقلیمی، رمس (*Hammada salicornica*)، مناطق بیابانی، ترسیب کربن، معادله رگرسیون