ECOPERSIA

DOI:10.18869/modares.Ecopersia.4.1.1283 **2016, 4 (1): 1283-1294**

Estimation of Aboveground Biomass Carbon Sequestration Potential in the Rangeland Ecosystems of Iran

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Received: 10 December 2015 / Accepted: 19 February 2016 / Published Online: 31 March 2016

ABSTRACT: Ongoing climate change has been a major global challenge since the 1880s. Sequestration of carbon(C) in rangelands ecosystems could provide a net carbon sink to offset increases in atmospheric C in global scale. This research is aimed at estimating the above-ground biomass carbon sequestration potential in Iran. For this purpose, total rangelands area and productivity data were extracted from the annual reports of Agriculture Statistical Pocketbook (2006-2013) of the country. Then productivity data was used to calculate above-ground C storage per province. The maximum and minimum rangeland areas were observed in Sistan and Baluchestan and Mazandaran (Nowshahr) Provinces, respectively. Maximum above-ground biomass C storage was about 1.07 Mg C$ha^{-1}y^{-1}$ in Fars Province. The minimum amount occurred in Qom province with only 0.023Mg C ha^{-1} y^{-1}. In summary, mean carbon CO_2fixation was about 0.25 Mg C ha^{-1} y^{-1}in Iran's rangelands from 2003 to 2013. Considering the total rangeland area(≈ 84.8 million hectare) and productivity of Iran, 11770.011 Gg C y^{-1} carbon is stored in above-ground biomass annually providing at least 5885 Gg organic C sequestration potential.

Keywords: *Carbon Fixation, Carbon sequestration, Iran, Productivity, Rangeland*

1 INTRODUCTION

During the last decade, climate change has turned into a public issue resulting from anthropogenic greenhouse gas (GHG)emissions with increase in global average temperature evident worldwide (Biello, 2007).Warming could induce some changes in precipitation via warmer air and greater evaporation potential, associated with the drying of terrestrial ecosystems (Easterling *et al.*, 2000; Huntington, 2006). Therefore, this is not only the matter of temperature, as precipitation pattern has been also changed both locally and globally (IPCC, 2014). The reality of unanimous climate-change induced warming, and drought is widely accepted (IPCC, 2007). The carbon dioxide emission in Iran has risen by 21.8 % only during the years 2007-2013 (Ghorbani *et al.*, 2014). The World Meteorological Organization (WMO) climate reports (2013) have announced several moderate to extreme drought events and +1°C temperature anomaly in Iran from 2001 to 2010. So, it is a time for immediate action to stop or at least mitigate the climate change consequences here in Iran. Considering that Iran is a major oil producer, it is among the top ten GHG emitting countries in the world that are responsible for two-third of global CO_2

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[DOR: 20.1001.1.23222700.2016.4.1.1.2]

production, occupied 9^{th} place in 2010 (Ghorbani *et al.*, 2014).

Carbon dioxide (CO_2) contribution to greenhouse gas emission is almost 58.8% (Bacon *et al.*, 2007). Hence, there is a global effort to cut the most prevalent GHG (CO_2, N_2O, CH_4)emissions, particularly C emissions, from different residential and industrial sectors to develop potential sinks and decrease potential sources of GHG (IPCC, 2007). One main solution is to capture and sequester atmospheric carbon dioxide (CO_2) into the biomass and soil organic matter of terrestrial ecosystems via photosynthesis process (IPCC, 2007; IPCC, 2014; Lu *et al.*, 2015). Comparing to different carbon capture and storage (CCS) projects, carbon sequestration costs in terrestrial lands are quite low, and could be offset by the co-benefits. Carbon sequestration depends on different parameters, including plant primary production and decomposition process. Equilibrium point is reached when input C sources (mainly Gross primary productivity) equal output carbons (respiration). So, the more input C sources outweigh the output C, the more carbon sequesters will be in terrestrial lands(IPCC, 2007; IPCC, 2014). Therefore, monitoring input and output carbon sources in ecosystems and land uses with great potential to sequester carbon is key to climate change mitigation (Attaeian, 2010). One such ecosystem that is predominant in Iran is the rangeland ecosystem.

Rangelands cover up to 80% of the global terrestrial ecosystems (Lund, 2007) and hold significant potential to capture and sequester carbon dioxide with the current rate of 0.5 Pg C y^{-1} (Schlesinger, 1997). The fact is that 20% to 73%of global rangelands are already degraded (Lund, 2007). Hence, the current rate of C storage in rangelands is much lower than their actual potential, which could be enhanced by reclamation practices. One more strong reason to make the rangeland ecosystem a suitable C sink is that rangeland plant species span a range of climate and region and are adapted to harsh natural disturbance. So, they could adapt to future climate changes more rapid than other plant species such as forests (Attaeian, 2010).

Rangelands occupy around 84.8 million hectare in Iran. Rangeland ecosystems cover up to 53 % of the total land in Iran, providing a great carbon sink to mitigate the effects of global warming in the local and global scales. The latest national classification report of Iran rangelands based on their productivity suggests that only 8.4% (7.2 million hectare)of these ecosystems are in good condition(Agriculture Statistical Pocketbook, 2013).Considering the vast area of rangeland ecosystems and their poor condition in Iran, these ecosystems provide significant carbon sinks' potential for carbon sequestration in Iran.

Since 2003, different integrated C sequestration projects in rangeland ecosystems have been running all across the country funded by Iranian Forests, Range and Watershed Management (FRWO) and UNDP, providing a successful model to enhance C sequestration in the country (Ghasemi Aryan, *et al.*, 2015). A number of studies have also revealed the potential of soil and plant of rangeland ecosystems to sequester atmospheric C. The average potential of carbon sequestration in the soil and plant phytomass was more than 2500 g m^{-2} in the rangeland ecosystems inthe Central Alborz, Iran (Alizadeh and Verdian, 2015). The density and cover of a plant species could influence the potential of soil carbon storage in rangeland ecosystems. A higher plant density provides a greater potential for C sequestration as suggested by Mahdavi *et al.* (2009) who studied carbon storage potential by *Atriplex lentiformis*. An increase of plant phytomass and productivity is equivalent to the higher carbon sequestration potential and vice versa (Schuman *et al.*, 2001; Sheidai Karkaj, 2011; Chen *et al.*, 2015). Thus, plant biomass estimation could

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enhance our understanding of C storage, and help to monitor carbon sequestration potential in natural ecosystems as suggested by Vashum and Jayakumar (2012). It can be concluded that among different carbon input sources, above-ground phytomass is mainly a large C pool directly influenced by climate and management. Therefore, above-ground phytomass could be seen as an easily manageable C sink in grazing systems.Sincethere is a gap of cross-country knowledge on carbon sequestration potential in Iran, this study aimed to estimate the potential of above-ground C storage in rangeland ecosystems across the country.

2 MATERIALS AND METHODS

2.1 Study area

Islamic Republic of Iran, consisting of 31 provinces (Figure 1), has almost 1,648,195 km^2area located between 32° 00' 00″ N and 53° 00' 00″E.The general climate is arid/semiarid mainlyin the East, West, and central regions while it spans from semi-humid in the North to subtropical in the South, covering four different bioclimatic zones, including Hyrcanian, Zagros, Iran-o-Toranian, Khalij-o-Omanian zones. The most dominant land type is mountain (46,036,179 ha). Because of the high diversity of topographical, climatic, and lithologic characteristics, Iran spans a rich mosaic of soil types (such as brown forest soil, chestnut soil, rendzinas, alluvial soils, and steppe soil series) (Eskandarian, 2012), and retains high plant diversity of about 8000 species (Ghahreman and Attar, 2000), with almost 1700 endemic covering fourdifferent ecological zones (Table 1) (as cited in Heshmati, 2007).

Table 1: Distribution of key rangeland species in four bioclimatic zones andprovinces

Bioclimatic zone	Province	Dominant plant species
Hyrcanian	Guilan, Mazandaran	*Onobrychis spp., Astragalus gossipinus, Agropyron spp., Bromus tomentelus, Artemisia spp., Dactylis glomerata, Poa spp., Trifolium partense, Tamarix ramosisima, Halostachys caspica, Halocnemum strobilaceum, Salicornia herbaceae*
Zagros	Lorestan, West Azerbaijan, Kermanshah, Kordestan, Ilam, Kohgiluyeh and Boyerahmad, Chaharmahal Bakhtiari, Fars	*Astragalus spp., Salvia spp., Agropyron spp., Festuca spp.*
Iran-o-Turanian	Kerman, Fars, Esfahan, Kordestan, Yazd, Ardebil, North Khorasan, South Khorasan, Razavi Khorasan, Sistan and Baluchestan, Semnan, Qom, Tehran, Markazi, Alborz, Qazvin, Zanjan, East Azerbaijan, Golestan, Hamedan,	*Artemisia spp., Artemisia siberi, Astragalus kavirensis, Astragalus gossypinus, Ephedra, Calligonum, Heliotropum rudbaricum, Tamarix spp., Aellenia spp., Halocnemum strobilaceum, Salsola spp., Haloxylon spp., Acantholimon spp., Alleum spp., Bromus tumentellus Haloxylon ammodenderon*
Khalij-o-Omanian	Khuzestan, Hormozgan, Bushehr, Sistan and Baluchestan,	*Medicago spp., Astragalus spp., Artemisia spp., Tamarix stricta, Euphorbia larica*

The altitude ranges from 56 m (at Chale Lut) to 5610 m (Damavand mount) with the average altitude being 1200 m above the sea level. Long-term mean annual precipitation is around 246 mm. As already mentioned, 84.8 million hectares (equal to 52.3 % of the total land area)

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are covered by rangeland ecosystems, following by desert (32.6 million hectares, 20.1%) and forest ecosystems (14.3 million hectares, 8.83%). Sheep and goat are the common livestock mainly depending on the rangeland ecosystems (Statistical and Technology Office, 2007). General rangeland management practices in the country are grazing, aromatic and medical plants, and fuel wood harvesting, clearing and conversion to arable and urban lands. Therefore, the rangeland degradation is accelerating due to overgrazing, early season grazing, and land-use changes, which have caused vegetation loss, bush encroachment, seed bank elimination, soil erosion, and finally, desertification.

2.2 Estimation of above-ground biomass carbon content

Several data sources were used to estimate the cross-country above-ground biomass carbon content in the country. For this purpose, data of the rangelands' total area and each class area (Table 2) per province and annual rangeland productivity (drymass kg ha^{-1}) were extracted from the Agriculture Statistical Pocketbook national annual report published by the Ministry of Agriculture Jihad, Iran from2006 to 2013.

Figure 1: Map of Iran and the provinces' positions.

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Table 2: Rangeland classification system productivity and vegetation cover

Rangeland class	Vegetation cover %	Aboveground(drymass kghay^{-1})
Good	50>	450
Fair	25-50	150
Poor	5-50	30

Data are approximate estimation based on different classification methods (Rabiei, 2014).

Finally, the carbon mass of the above-ground biomass in each province was calculated using the following Eq. (1) (Winrock, 1997):

$$OC = 0.55 \times \text{biomass} \quad (1)$$

This is a widely accepted coefficient to estimate organic carbon content in plant tissue (FAO, 2004).

3 RESULTS

3.1 Total area of rangeland ecosystems

As the results show, the rangeland ecosystems are unevenly distributed across the country (Figure 2). The maximum rangeland area was observed in Sistan and Baluchestan Province. Total land area in Sistan and Baluchestan is 181,785 km^{2}that rangelands cover around 10648499 ha (≈58.5%) of the province. However, Sistan and Baluchestan covers mostly poor condition rangelands (Figure 2). In contrast, the minimum poor condition rangelands (9318 ha) are located in Mazandaran (Nowshahr), a province with the minimum area of rangeland across the country. It is tobe mentioned that Mazandaran (Nowshahr and Sari Cities) and Gilan Provinces are mainly dominated by forests not rangeland ecosystems (Figure 2).

Furthermore, the maximum and minimum areas of fair rangelands were observed in Kerman (2214046ha) and Qom (34830 ha) Provinces, respectively. In addition, the minimum area of good condition rangelands was evident in Hormozgan, covering only 0.01 % of the total land area in the province. East Azerbaijan has the maximum area of the good rangeland in the country by 703729 ha (Figure 2).

Overall, the total area of rangelands in poor, fair and good conditions was around 56214591 ha, 21419152 ha, and 7181251 ha (8.4%), respectively.

Carbon sequestration potential in above-ground biomass

Above-ground biomass carbon content in the rangeland ecosystems was calculated by multiplying annual productivity (drymass) per province (Figure 3) by 0.55 (Equation 1). Also because there were no separate drymass data available for newly established provinces (i.e.Alborz, South Khorasan, North Khorasan, and Razavi Khorasan) as well as Kerman (south), they were embedded in Tehran, Khorasan and Kerman Provinces.

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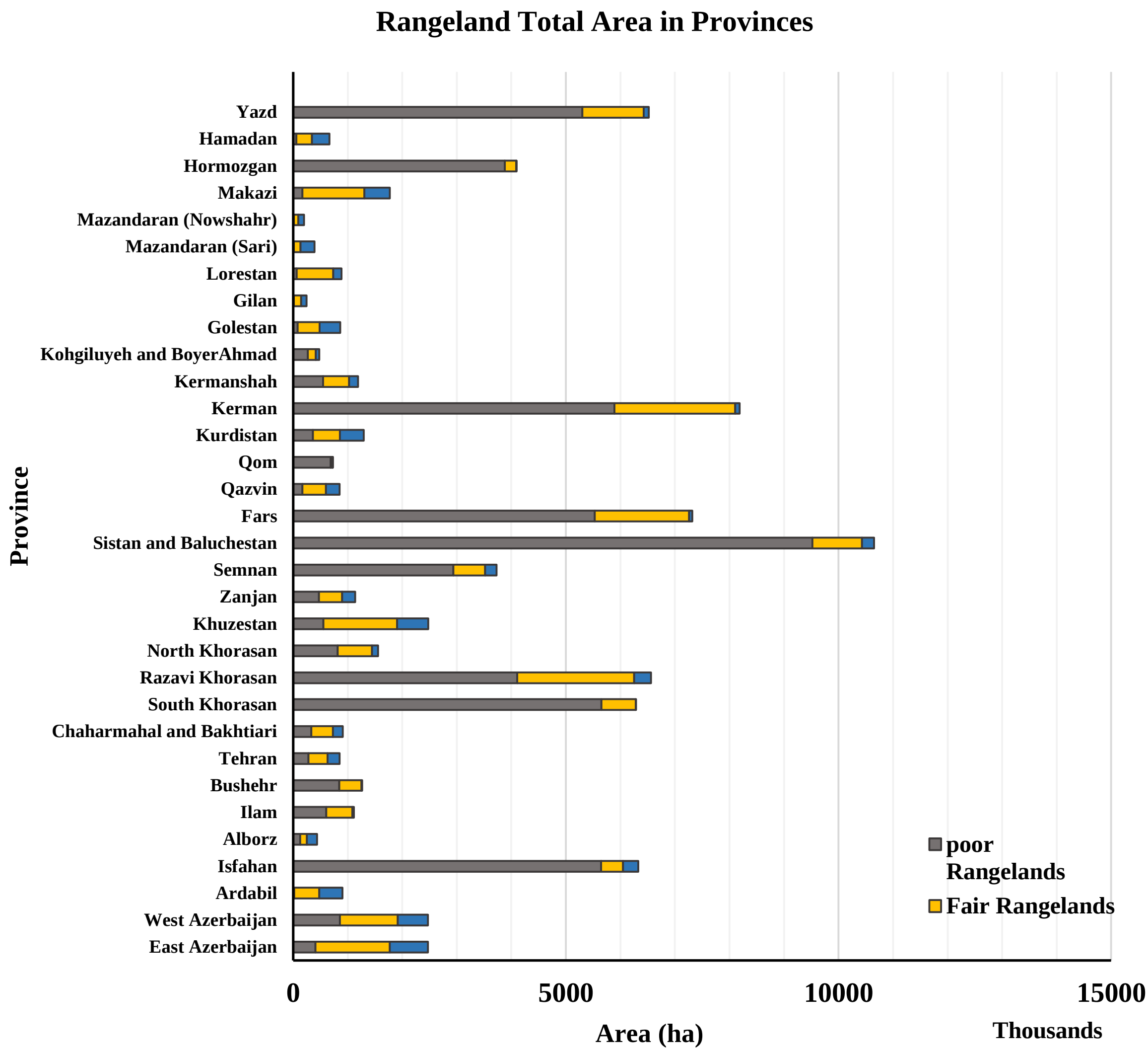

Figure 2: Total area of rangeland ecosystems in different provinces as classified inpoor, fair, and good conditions.

The results showed that the maximum above-ground biomass Cstorage (1.07 Mg C $ha^{-1}y^{-1}$) occurred in Kohgiluyeh and Boyerahmad Province (Figure 4) where rangelands cover up to 30.88% of the province. The minimum amount belonged to Yazd Province with only 0.021 Mg C ha^{-1} y^{-1} carbon storage (Figure 4). Overall, the average carbon storage in above-ground biomass was about 0.25 Mg C ha^{-1} y^{-1} in Iran's rangeland ecosystems during the last decade (Figure 4).

Considering the total rangeland area in each province, a total carbon of 11770.011 Gg Cy^{-1} has been captured through photosynthesis process in the above-ground biomass of the rangeland ecosystems across the country. Almost 10123.7 Gg C y^{-1} of the total amount sequestered under Iran-o-Turanian bioclimatic zone, which is dominated by *Artemisia spp. Astragalus spp., Ephedra, Calligonum, Heliotropum spp., Tamarix spp., Aellenia spp., Halocnemum strobilaceum, Salsola spp.,*

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*Haloxylon spp., Acantholimon spp.,*and *Alleum spp.* plant species.

Due to grazing practices in the rangelands, at least 50% of this organic C (Agriculture Statistical Pocketbook, 2013) is annually harvested in the rangelands as shown in Figure 4. Therefore, half of the organic C storage in above-ground biomass would be mostly added to the soil for C sequestration (5885.006 Gg C y^{-1}). So, a total amount of 5885 Gg organic C would annually be added to the rangeland soils, providing a sustainable source of C sequestration in these ecosystems in Iran.

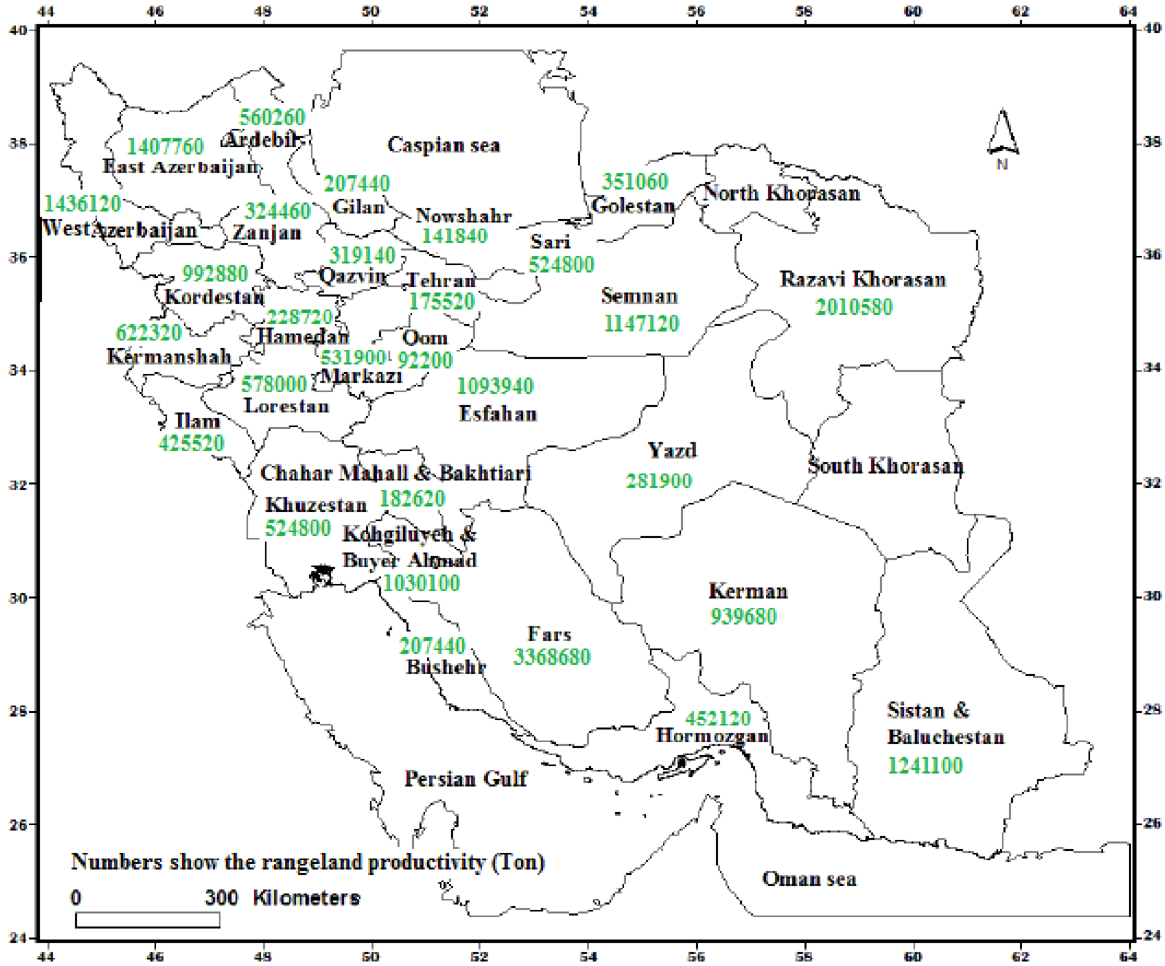

Figure 3: Annual mean productivity of rangeland ecosystems in Iran in 2006-2013.

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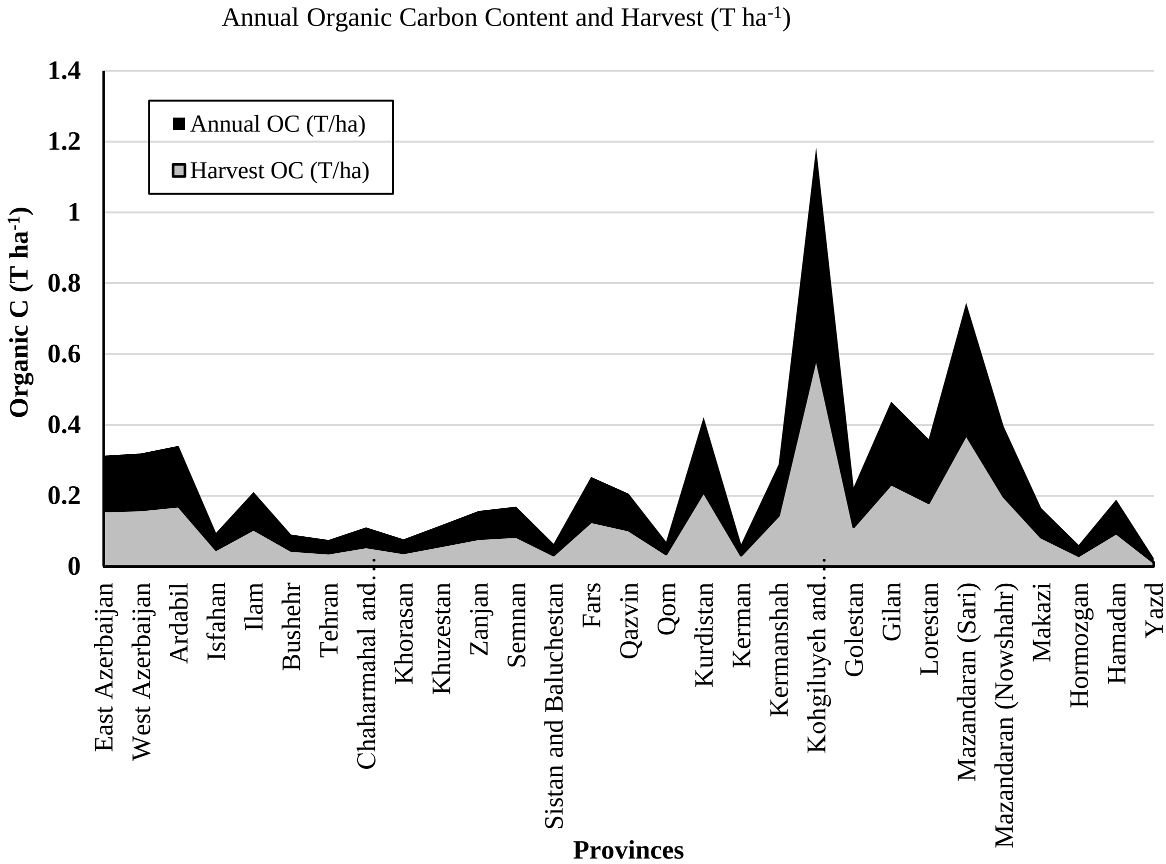

Figure 4: Annual carbon sequestration potential in aboveground biomass in the rangeland ecosystems of Iran in 2006-2013

4 DISCUSSION

The current research estimated a rate of 11770.011 Gg annual atmospheric carbon storage in the rangeland ecosystems in Iran of which at least 5885 Gg C could sequester into the soil via litter addition and decomposition process. However, a deeper understanding of C cycling in rangeland ecosystems seems necessary for accurate estimation of the C sequestration potential in Iran. For example, more information of soil C respiration and microbial activity in rangelands could help for better evaluation of C sequestration in Iran. Because even small changes in the microbial community function in these rangeland ecosystems might have important implications for global C sinks (Attaeian, 2010).Rangelands are significant global carbon sinks due to their high root biomass, which can reduce the risk of fire and decomposition kinetic comparing to above-ground biomass (Hunt *et al.*,2002).Regardless of the lack of information on below-ground process in rangeland ecosystems in Iran, this research revealed that rangelands are generally a net C sink as also suggested by previous researches locally and globally (e.g., Ciais *et al.*,1995; Pacala *et al.*,2001; Lund, 2007; Sheidai Karkaj, 2011; Alizadeh and Verdian, 2015).

Carbon dioxide emission was around 600 million tons from power plant and other sectors in 2013 in Iran. Considering the results of the

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present study, the actual potential of cross-country C storage in above-ground biomass in the rangelands (11770.011 Gg Cy^{-1}) was only about 1.96% of the CO_2 emission in 2013. Also atmospheric carbon level in the atmosphere (≈ 15 t C ha^{-1}) is much higher than the average organic carbon capture (0.25 t C ha^{-1})in above-ground biomass in Iran's rangelands. However, this is the minimum amount of C sequestration potential in the rangeland ecosystems in Iran, because no data for root biomass was available. Considerable phytomass is allocated to plant roots in the rangeland ecosystems, providing a major potential for C sink(Chen *et al.*, 2006; Tamartash *et al.*, 2014). More importantly, 66% and 25.25 % of rangelands are in poor and fair conditions (Figure 3), respectively, in Iran. This means that their primary productivity is much lower than their actual potential for plant production, and consequently, C sequestration in Iran. Considering this fact that 91.25 % of the rangeland ecosystems in Iran are degraded, the current rate of 11770.011 Gg Cy^{-1} is below the maximum potential of these ecosystems. Furthermore, comparing the current rate of C sequestration that is500,000 Gg C y^{-1} (Schlesinger, 1997) in terrestrial lands, carbon sequestration rate in Iran's rangelands (11770.011 Gg C y^{-1})is much lower than the global average (≈ 2.3%).So, the carbon sequestration potential could be much higher in the country.

Itis widely accepted that rangeland ecosystem are less susceptible to climate change, and could maintain overall ecosystem function in future climate changes, providing a reliable source for C sink (Schuman *et al.*, 2001; Lal, 2004; Lund, 2007; Attaeian, 2010; Sheidai Karkaj, 2011; IPCC, 2014; Alizadeh and Verdian, 2015). As the increasing trend both in CO_2 emission (Ghorbani *et al.*, 2014) and rangeland degradation (Moghadam, 1998) is threatening the economy, human health, and sustainable development in Iran, it is the right time for immediate action. In addition, C fluxes are likely to change with climate change and land management practices. Therefore, a proper management of Iran's rangelands (e.g., intensity and timing of grazing) is crucial to control the plant productivity, litter decomposition, nutrient cycling, and enhancing C storage level in these systems. Although the current study confirmed that the rangelands are a C sink in Iran, but with the current rate of C storage, these ecosystems could not play a significant role in C sequestration in the country/world. Therefore, the reasons of low above-ground C storage of the rangelands across the country should be investigated to enhance C sequestration in them. Monitoring rangeland ecosystems, studying different organic C compartments, setting multi-factor experiments, and extrapolating the observations to natural systems are key steps to promote mitigation strategies in Iran's rangeland ecosystems where the actual rangeland C sequestration potential is beyond the current rate due to their degradation and poor condition.

5 CONCLUSION

The mean annual carbon sequestration rate of above-ground biomass was around 11770.011 Gg C y^{-1} with the maximum(1.07 Mg C ha^{-1} y^{-1}) and minimum amounts (0.021 Mg C ha^{-1} y^{-1}) occurring in Kohgiluyeh and Boyerahmad and Yazd Provinces, respectively. Because of the rangeland degradation and vegetation decreases in Iran, the current rate of above-ground C sequestration in the rangelands of Iran is much lower than the global average rate. So, proper rangeland management techniques and avoiding overgrazing can enhance above-ground C sequestration rate in the country.

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تاریخ دریافت: ۱۹ آذر ۱۳۹۴ / تاریخ پذیرش: ۳۰ بهمن ۱۳۹۴ / تاریخ چاپ: ۱۲ فروردین ۱۳۹۵

چکیده از دهه هشتاد میلادی، تغییرات اقلیمی یکی از چالش‌های بزرگ جهانی بوده است. ترسیب کربن در اکوسیستم‌های مرتعی را می‌توان یک منبع ذخیره کربن جهت تعدیل کربن اتمسفری در مقیاس جهانی دانست. تحقیق حاضر با هدف برآورد پتانسیل ترسیب کربن در زیتوده هوایی مراتع در ایران انجام شده است. به همین منظور، اطلاعات سطح و تولید مراتع از گزارشات سالانه آمارنامه کشاورزی کشور (۱۳۹۲-۱۳۸۵) استخراج شدند. سپس با استفاده از اطلاعات تولید مراتع، ذخیره کربن اندام هوایی در هر استان محاسبه شد. بیشترین و کمترین سطح مراتع به‌ترتیب در استان‌های سیستان و بلوچستان و مازندران (نوشهر) مشاهده شد. حداکثر کربن ذخیره شده در زیتوده هوایی در کشور در استان فارس مشاهده شد که معادل ۱/۰۷ مگاگرم کربن در هکتار در سال برآورد شد. حداقل این پارامتر برابر ۰/۰۲۳ مگاگرم کربن در هکتار در سال بوده که در استان قم مشاهده شد. به طور خلاصه، متوسط کربن ذخیره شده در زیتوده هوایی مراتع ایران بین سال‌های ۱۳۸۵ تا ۱۳۹۲ برابر ۰/۲۵ مگاگرم کربن در هکتار در سال می‌باشد. که با احتساب تولید کل و وسعت مراتع کشور (≈ ۸۴/۸ میلیون هکتار) کربن ذخیره شده در زیتوده هوایی مراتع برابر ۱۱۷۷۰/۰۱۱ گیگاگرم کربن در سال است و حداقل ۵۸۸۵ گیگاگرم کربن آلی سالانه در این اکوسیستم‌ها ترسیب می‌گردد.

کلمات کلیدی:ایران،ترسیب کربن، زیتوده هوایی، مراتع

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[DOR: 20.1001.1.23222700.2016.4.1.1.2]