Iran Agricultural Research (2019) **38**(**2**) 47-54

Shiraz University

Carbon sequestration in sugarcane plant and soil with different cultivation systems

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DOI: 10.22099/iar.2019.30598.1295

ARTICLE INFO
***Article history*:**
Received **27 August 2018**
Accepted **4 May 2019**
Available online **13 January 2020**

Keywords:
Climate change
Khuzestan Province
Ratooning cultivation system
Soil organic carbon

ABSTRACT- Sugarcane (*Saccharum officinarum* L.) is a multi-purpose crop, mainly planted in South-western (SW) parts of Iran. However, the capability of sugarcane farms to sequestrate carbon into soil and plant is not well documented. In this research, the carbon sequestration in sugarcane plant and soil in a ratooning traditional cultivation system at the Amirkabir Sugarcane Agro-Industry Complex in Khuzestan Province was evaluated during 2013-2014. The soil samples were randomly collected at 0-30 cm top layer and soil organic carbon (SOC) was analysed in laboratory. Simultaneously, both aboveground and underground parts of sugarcane plants were sampled and the carbon content of each part was measured separately. The carbon stored in the aboveground parts (leaves and shoots) was significantly ($p \leq 0.01$) higher (1292 kg ha^{-1}) than that (655 kg ha^{-1}) of underground organs (roots). The total SOC (1987.3 kg ha^{-1}) was not considerably higher than the sequestrated carbon (1947 kg ha^{-1}) in plant parts. Furthermore, a positive and significant correlation was found between SOC and soil clay content. Overall, 3934.5 kg ha^{-1} sequestrated carbon equal to 14439.6 kg ha^{-1} atmospheric CO_2 was estimated to be in sugarcane farms. In conclusion, the results showed that the Ratoon I has the highest potential of carbon sequestration than other treatments. Current sugarcane farming practices in Khuzestan could act as an important pool for carbon sequestration and consequently enhancing the mitigation of climate change impacts. It seems that changing the current sugarcane traditional harvesting system which is predominantly based on burning the residues towards the suitable management could enhance the capability of carbon sequestration even more.

INTRODUCTION

The leading cause of climate change is the growing concentration of greenhouse gasses (GHGs), including carbon dioxide (CO_2) mainly emitted from human unsustainable activities (D'Alessandro et al., 2010). As Intergovernmental Panel on Climate Change (IPCC, 2015) reported, the earth surface temperature is expected to rise by 1.4 °C to 5.8 °C at the end of the century as a result of GHGs emission. In order to stabilize the global temperature, the anthropogenic CO_2 has to be mitigated to a significant level (Davis et al., 2010) and the surplus atmospheric CO_2 in plants, soil and the oceans has to be sunk. One of the sustainable approaches might be enhancing the CO_2 capture by extending natural vegetation and sustainable farming practices (Scharlemann et al., 2014; Falloon et al., 2009; Sadeghi and Raeini, 2016). Cropland soils as important carbon sinks (Buyanovsky and Wagner, 1998; Nadeu et al., 2015) play a potentially significant role in atmospheric carbon reduction (Lal, 2001; D'Alessandro et al., 2010).

Sugarcane is a perennial grass cultivated economically and commercially in over 90 countries with widespread global area of approximately 26×10^6 ha and worldwide harvest of 1.83 billion tones (Anaya and Huber-Sannwald, 2015; FAOSTAT, 2016). Sugarcane is mainly used for sugar production. It is also used for livestock feeding and producing ethanol as a biofuel (Goldemberg, 2007). However, in many countries in an unsustainable conventional management, the leaves and trashes of this crop are burned to facilitate harvesting (Anaya and Huber-Sannwald, 2015). This leads the emission of GHGs, particularly CO_2. Burning leaves and litters also releases soot and charcoal to the atmosphere causing health problems (Cancado et al., 2006; Galdos et al., 2009).

Previous studies have indicated that leaving sugarcane leaves and trashes on soil instead of burning them improves physical, chemical and biological characteristics of soil (Meier et al., 2006).

Leaving the sugarcane residues on the soil improves soil biological activity (Singh and Sharma, 1991; Yadav et al., 1994), decreases soil bulk density (Tominaga et al., 2002), enhances soil aggregation stability and infiltration rate (Graham et al., 2002; Galdos et al., 2009) and reduces gas emissions compared to the traditional burning harvesting system. For example, a farm with burned residues had 30% lower carbon content particulate organic matter and microbial biomass carbon than those of a farm where the trashes and residues were left on the soil. It was reported in Brazil that the total carbon stocks were also greater in unburned treatments (Galdos et al., 2009; Cerri et al., 2011). A survey in Brazil also showed that leaving the sugarcane residue biomasses in soil returned a remarkable organic matter compared to the soils where the sugarcane residues were burned (de Figueiredo et al., 2010). On the other hand, heavy sugarcane biomasses in above and underground parts of the soils could act as important pools for carbon sequestration and consequently enhancing the mitigation of climate change impacts. However, there is not much research carried out on the capability of carbon sequestration in sugarcane farms in Iran. This study therefore was conducted to examine the status of carbon sequestration in sugarcane farmlands in South-western parts of Iran.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted at the Amirkabir Sugarcane Agro-Industry Complex (ASAIC), (N 31° 01´, E 48° 17´, 7 m abs) in Khuzestan Province, Iran. The total area of sugarcane cultivation was about 8890 ha in a flat plain managed with plant and ratooning cultivation system. The site climate was classified as BWh according to Köppen-Geiger system (Kottek et al., 2006) with mean annual precipitation of 213 mm, and mean annual temperature of 24.9 C°. The soil texture was clay-loam and loam, with alluvial origin. The mean soil pH and electrical conductivity (EC) at top 30 cm was 7.4 and 2.75 dSm^{-1}, respectively with bulk density (BD) of 1.63 g cm^{-3}. The experiment was conducted based on a completely randomized design with five treatments and three replications (see below).

Soil Sampling and Laboratory Analysis

Soil samples were taken randomly from 0-30 cm depth with three replications, using a hand soil auger (diameter 60 mm) in each of the five treatments, namely planted cane (PC), ratoon-I (R-I), ratoon-II (R-II), ratoon-III (R-III) and ratoon-IV (R-IV), respectively. The first cultivation stage started in August of the first year until the next October at the second year that was the first harvesting stage in sugarcane farms (Plant cane, PC). After harvesting in October, the plants reproduced sprouts and grew between 10 to 12 months that was the suitable time for harvesting (Ratoon-I). The second to fifth harvesting stages were known as the Ratoon-II to Ratoon IV. The air-dried soil samples were sieved through a 2-mm screen and prepared for analysis in the soil laboratory of ASAIC. Soil texture was determined using the hydrometer method (Bouyoucos, 1962). Soil pH was determined using an electric pH meter (Page et al., 1982) and electrical conductivity (EC) was determined from a 1:1 soil-water suspension using an electric conductivity meter (Carter, 2008). Soil bulk density was determined using a core sampler of 8 cm diameter and soil organic carbon (SOC) was measured using Walkley-Black method (Nosetto et al., 2006).

Plant Sampling and Laboratory Analysis

Five plant samples were taken from the five treatments randomly, each within an area of 1 m^2 before the harvesting time at the end of the growth stage at each treatment The plant samples were weighted immediately to estimate the ground biomass. The leaves and stems were subsequently separated and dried in an oven at 85 °C for 48 hrs, and then re-weighted. The plant underground parts including roots and basal parts were also sampled within the depth of 0-50 cm and dried in an oven and then weighted accordingly. In order to determine plant organic carbon, the leaves, stems and roots were hammer-milled to pass through a 0.5 mm sieve mesh. The carbon content was then determined using a CHN analyzer (Flash EA 1112 series, Thermo Finnigan model), and the mean values were utilized using the statistical analysis in a completely randomized design experiment.

Statistical analysis was carried out using the ANOVA procedure, and significant differences between the means were determined by Duncan's multiple range tests with *P*-value of 0.05 and 0.01 as significant levels, using SPSS program version 19.0 (IBM Corp. 2010). Correlation coefficients were calculated by Minitab software version 16.1 (Minitab 16 Statistical Software, 2010).

RESULTS AND DISCUSSION

Soil Properties and Carbon Storage

The results showed that, some soil physical properties, including sand, silt and BD were significantly different in different cultivation systems. The soil chemical properties including EC and pH, were significantly different (Table 1). The results of ANOVA showed that different cultivation systems had a considerable effect on SOC storage (Table 1).

The highest soil sand content (66.83%) was obtained in Ratoon IV treatment. Inversely, the silt content of 13% in Ratoon IV treatment was significantly different from those of other treatments (Table 2). However, there was no difference in soil clay content between the experimental sites. The soil EC in planted cane treatment (5.89 dSm^{-1}) was much higher (nearly three times) than that of the EC of the samples taken from other treatments of R-I (1.72), R-II (1.76), R-III (1.84) and R-IV (1.94), respectively.

Table 1. Results of ANOVA showing the effect of the cultivation system (PC, R-I, R-II, R-III and R-IV) on soil properties

		Mean square						
Source of variation	Degree of freedom	Sand (%)	Silt (%)	Clay (%)	EC (dSm^{-1})	pH	BD (gcm^{-3})	SOC (%)
Treatment[1]	4	571.06**	468.20**	45.12ns	9.49**	0.34**	0.05**	0.046**
Error	10	21.66	40.62	28.81	0.57	0.01	0. 003	0.001
±SE[2]		3.45	3.29	1.49	0.43	0.07	0.03	0.03

[1]Treatments: PC, R-I, R-II, R-III and R-IV; [2] Standard error; ns: non-significant; **Significant at ($p \leq 0.01$).

Table 2. Mean comparison of the effect of different cultivation systems (PC, R-I, R-II, R-III and R-IV) on soil properties and SOC storage.

	Soil properties (Mean±SD[1])						
Trt[2]	Sand (%)	Silt (%)	Clay(%)	EC ($dS\ m^{-1}$)	pH	BD($g\ cm^{-3}$)	SOC (%)
PC	35.50^b±2.00	41.00^a±2.00	23.5^a±0.01	5.89^a±1.00	7.81^a±0.09	1.70^a±0.01	0.27^d±0.02
R-I	37.83^b±0.57	43.75^a±6.80	18.42^a±6.23	1.72^b±0.05	7.47^b±0.10	1.71^a±0.02	0.18^e±0.04
R-II	36.16^b±4.61	40.00^a±2.78	23.84^a±3.01	1.76^b±0.22	7.37^{bc}±0.14	1.40^b±0.04	0.43^b±0.02
R-III	34.83^b±6.42	36.66^a±9.64	28.50^a±3.27	1.84^b±0.41	7.14^c±0.15	1.67^a±0.04	0.54^a±0.01
R-IV	66.83^a±6.42	13.00^b±7.21	20.17^a±9.23	1.94^b±0.18	7.21^{bc}±0.23	1.67^a±0.03	0.34^C±0.03

[1]SD: Standard deviation; [2]Treatment; Means followed by the similar letters within one column do not differ significantly (Duncan 1%).

This might be due to salt leaching in top layers during different cultivation years. Soil pH value showed 7.14, 7.21, 7.37, 7.47 and 7.81 which belonged to R-III, R-IV, R-II, R-I and PC treatments, respectively (Table 2). The comparison of soil BD in different treatments indicated that the lowest (1.40 gcm^{-1}) and the highest (1.71 $gcm^{-1)}$ values of BD belonged to the R-II and R-I treatments, respectively. The organic carbon of the soil was significantly different with the lowest value of 0.18% in R-I and the highest value of 0.54% in R-IV treatment (Table 2).

Plant Carbon Storage

The carbon stocks in different sugarcane plant parts, including roots, shoots and leaves were significantly ($p \leq 0.01$) different (Table 3). The highest amount of carbon stock was found in leaves (877.0 kg ha^{-1}) and roots (655.3 kg ha^{-1}) while the carbon stock in shoots demonstrated the lowest value of 414.7 kg ha^{-1} showing that 11% and 24% more carbons were stored in the leaves compared to the roots and shoots (Table 4).

Table 3. Results of ANOVA showing the effect of sugarcane organs on carbon sequestration

Source of variation	Degree of freedom	Mean square (kg ha^{-1})
Sugarcane organs	2	267347.89**
Error	12	974.99
CV(%)[1]		4.51

[1] Coefficient of variation; **Significant at ($p \leq 0.01$)

Means followed by similar letters within one column do not differ significantly (Duncan 1%) The total carbon storage in sugarcane biomass including aboveground parts (shoots and leaves) and belowground part (roots) in different cultivation systems was significantly different at 1% probability level (Table 5).

The highest and the lowest root carbon stock of cultivation systems belonged to R-I (937.61 kg ha^{-1}) and R-IV (433.93 kg ha^{-1}), respectively. The stored carbon in shoots of R-I cultivation system (698.09 kg ha^{-1}) was the highest compared to that in other cultivation systems. The carbon stored in leaves of R-I cultivation system (1157.31 kg ha^{-1}) and in PC cultivation system (538.53 kg ha^{-1}) indicated the highest and the lowest values compared to the other cultivation systems (Table 6).

Table 4. Mean comparison of the effect of different sugarcane organs on stored carbon

Sugarcane organs	Stored carbon±SD (kg ha^{-1})
Roots	655.37^b±24.4
Shoots	414.74^c±22.5
Leaves	877.08^a±42.5

Table 5. Results of ANOVA showing the effect of the cultivation system on carbon sequestration

		Mean square		
Source of variation	Degree of freedom	Roots (kg ha^{-1})	Shoots (kg ha^{-1})	Leaves (kg ha^{-1})
Treatment[1]	4	64021.61**	386757.21**	529192.38**
Error	8	556.55	111.47	30192.96
CV(%)[2]		3.7	2.47	7.38

[1]Treatments: PC, R-I, R-II, R-III and R-IV; [2] Coefficient of variation; **Significant at ($p \leq 0.01$).

Overall, the stored carbon (2793 kg ha^{-1}) in plants cultivated in R-I cultivation system was about twice as much as that in the plants in PC cultivation system and 1.4 times as much as that in the plants of the other cultivation systems (Table 6). In total, the stored carbon

(2793 kgha^{-1}) in plants cultivated in R-I was about 203.2% more than that in the plants in PC cultivation system (13740 kgha^{-1}) and 140% to 150% more than that in the plants of the other cultivation systems (Table 6). The highest amount of carbon sequestration in leaves belongs to the Ratoon-IV with 53.97% (Table 6).

There was a positive and significant correlation between SOC and clay content while the sand content and BD showed a significant and negative correlation with SOC (Table 7).

In general, the estimated carbon stored in sugarcane organs was 1947.2 kg ha^{-1} while the estimated carbon stored in the soil was 1987.3 kg ha^{-1} (Table 8). The equivalent sequestrated carbons (CO_2) in sugarcane organs and in the soil (using a coefficient of 3.67 as IPCC, 1996 recommended) were 7146.2 and 7293.4 kg ha^{-1}, respectively. This made a total estimation of 14436.6 kg ha^{-1} CO_2 sequestration by both plant and soil in sugarcane farming system in the study area (Table 8).

The total carbon storage in various cultivation systems was notably different in this study. Soil organic carbon is affected directly by the farm management practices such as crop type, manure application, tillage intensities, irrigation efficiency, harvesting approaches and the life period of crop plants (West and Marland, 2002; Freibauer et al., 2004; Smith, 2004). It has been reported that soil texture and in particular clay content have a key role in capability of soil carbon sequestration (Reeder and Schuman, 2002). The results of this research confirmed that R-III cultivation system with higher clay content (28.5%) compared to other cultivation systems tested in this study showed more carbon storage (36%) than other treatments. This is consistent with the results reported by Ghanbarian et al. (2015) and Sadeghi and Raeini (2016) in Iran and Li et al. (2010) in China.

However, according to another research, soil BD and sand content had negative effects on soil carbon storage (Suman et al., 2009). The R-II and R-IV treatments demonstrated approximately similar soil properties, except for BD and sand content; Accordingly, a negative correlation was found between soil BD and sand content with SOC values (Tables 2 and 7). The results revealed that R-II treatment with lower soil BD and higher sand content compared to other treatments had a higher capability (9%) to sequestrate carbon (Tables 2 and 7). This result is in agreement with the results of a study conducted by Suman et al. (2009) who reported that reduction in soil BD would lead to increase in SOC of sugarcane farms. It seems that the differences in chemical and physical properties of soil in different cultivation systems as outlined above might have caused the considerable differences in soil organic carbon content.

The results of this study also indicated that sugarcane leaves and roots had higher carbon storage than shoots (Tables 4 and 6). Several studies have found that perennial plants with woody organs had higher potential to reserve the organic carbon compared to annual plants (Gao et al., 2007; Ghanbarian et al., 2015; Sadeghi and Raeini, 2016). Overall, 1292 kg ha^{-1} (66%)) carbon storage belonged to the aboveground plant organs and 655 kg ha^{-1} (34%) belonged to the roots (Tables 4 and 6) of sugarcane showing that the considerable carbon storage capability of sugarcane (Table 6 and 8).

Table 6. Carbon storage of sugarcane organs in different cultivation systems (PC, R-I, R-II, R-III and R-IV)

	Stored carbon (Mean±SD[1])						
	Roots		Shoots		Leaves		Total
Treatment	(kg ha^{-1})	(%)	(kg ha^{-1})	(%)	(kg ha^{-1})	(%)	(kg ha^{-1})
Planted cane	615.34^{b}±7	44.78	220.40^{e}±3	16.04	538.53^{b}±39	39.19	1374.27
Ratoon-I	937.61^{a} ±14	33.57	698.09^{a}±7	24.99	1157.31^{a}±85	41.44	2793.01
Ratoon-II	594.79^{C}±6	32.65	430.05^{b}±4	23.61	796.76^{b}±59	43.74	1821.60
Ratoon-III	701.96^{b}±8	36.11	320.44^{d}±3	16.48	921.50^{b}±68	47.40	1943.90
Ratoon-IV	433.93^{d}±5	23.98	399.15^{c}±2	22.05	976.81^{b}±72	53.97	1809.89

Means followed by similar letters within one column do not differ significantly (Duncan 1%).

Table 7. Correlation coefficients among different soil properties and SOC%

	Sand (%)	Silt (%)	Clay (%)	EC (dS m^{-1})	pH	BD (g cm^{-3})	SOC (%)
Sand (%)	1.000						
Silt (%)	-0.903**	1.000					
Clay (%)	-0.319^{ns}	-0.119^{ns}	1.000				
EC (dSm^{-1})	0.233^{ns}	0.635**	0.137^{ns}	1.000			
pH	-0.382^{ns}	0.739**	-0.210^{ns}	0.664**	1.000		
BD (gcm^{-3})	0.187^{ns}	0.091^{ns}	-0.231^{ns}	0.352^{ns}	0.112^{ns}	1.000	
SOC (%)	-0.641**	0.342^{ns}	0.711**	-0.106^{ns}	-0.234^{ns}	-0.532*	1.000

**Significant at ($p \leq 0.01$); *significant at ($p \leq 0.05$), ns: non-significant;

Table 8. Carbon sequestration and equal to CO_2 in plant organs and soil in sugarcane farm

	Stored carbon (kg ha^{-1})					CO_2 equal (kg ha^{-1})[a]		
Mean	Roots	Shoots	Leaves	Soil	Total (Soil and Plant)	Plant (All organs)	Soil	Total (Soil and Plant)
	655.37	414.74	877.08	1987.3	3934.5	7146.2	7293.4	14439.6

[a] Assuming 1 t of stored carbon is equal to 3.67 t CO_2 in atmosphere , multiplication factor 3.67 was used to estimate CO_2 equivalent according to IPCC (1996); Bikila et al. (2016).

Previous research showed that this carbon remains in field between 3 to 6 years before re-plantation (Chandra et al. 2008; Galdos et al., 2009; Suman et al., 2009; Cerri et al., 2011). However, these results are not in agreement with those of Jafarian and Tayefeh (2013) who reported higher carbon sequestration in spikes and shoots and lower carbon content in leaves and roots of wheat (*Triticum aestivum*) in Kiasar, Iran. This could be attributed to the fact that wheat is an annual herbaceous crop compared to sugarcane which develops woody structural tissues.

Generally, the results of this study indicated that sequestration of carbon in sugarcane farms was 1947.2 and 1987.3 kg ha^{-1} in plant and soil, respectively which was equal to 7146.2 and 7293.4 kg $ha^{-1}y^{-1}$ CO_2 in plant and soil, respectively. In other words, the plant and soil systems in sugarcane farmland were capable of sequestrating 14439.6 kg ha^{-1} of atmospheric CO_2 per year. Burning sugarcane residues is a communal practice in the region. A recent research study on sugarcane conducted in the same region indicated that on average, 7200 kg $ha^{-1}$of CO_2 was released to the atmosphere due to the traditional agricultural practices (Sefeedpari et al., 2014). This is nearly half of the total sequestrated carbon in the same area of a sugarcane field which estimated in this study (Table 8).

CONCLUSION

The present study revealed that sugarcane is a substantial carbon pool in south-west (Khuzestan) of Iran. Traditional agricultural practices, especially burning leaves and trashes may contribute to releasing GHGs to the atmosphere in addition to enhancing soil organic carbon loss and air pollution. In ratoon crop system with green harvesting as a result of high biomass accumulation, the crop residues could remain on top soil layer for several years which would help to protect the soil against wind and water erosion, promote soil and crop productivity, reduce water loss and reinforce carbon storage in sugarcane fields. Overall, the results of this study showed a promising effect of sugarcane cultivation on carbon sequestration. However, to ensure the validation of such a claim, it is recommended that this study be continued over one full cycle of sugarcane cultivation. It would be worth evaluating and comparing green and burn-harvesting systems with respect to their capability to sequestrate carbon. The objective would be to encourage farmers to change their management procedures towards environmentally friendly agricultural activities.

ACKNOWLEDGEMENT

The sincere assistant of all members in the soil laboratory and the farmlands of Amirkabir Sugarcane Agro-Industry Complex (ASAIC) is highly appreciated. We would like also to thank Dr. Hassan Hamdi for his effective collaboration during this study.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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تحقیقات کشاورزی ایران (۱۳۹۸) ۳۸(۲) ۴۷-۵۴

ترسیب کربن در گیاه و خاک مزارع نیشکر در سیستم‌های مختلف کشت

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اطلاعات مقاله

تاریخچه مقاله:
تاریخ دریافت: ۱۳۹۷/۶/۵
تاریخ پذیرش: ۱۳۹۸/۲/۱۴
تاریخ دسترسی:۱۰/۲۳/ ۱۳۹۸

واژه‌های کلیدی:
تغییر اقلیم
استان خوزستان
سامانه کشت راتونینیگ
کربن آلی خاک

چکیده- نیشکر گیاهی چند منظوره است که عمدتاً در قسمت‌های جنوب غربی ایران کشت می‌شود. تاکنون در مورد قابلیت ترسیب کربن مزارع نیشکر ایران پژوهش‌های کافی صورت نگرفته است. در این پژوهش، ترسیب کربن در اندام‌های گیاه و خاک مزارع تحت کشت نیشکر در خوزستان که به روش سنتی راتونینگ کشت و برداشت می‌شوند مورد ارزیابی قرار گرفت. به این منظور، نمونه‌های خاک از لایه سطحی ۳۰-۰ سانتی‌متری به صورت تصادفی برداشت و میزان کربن آلی، اسیدیته، هدایت الکتریکی، بافت و وزن ویژه ظاهری آن‌ها تعیین شد. به صورت همزمان از اندام‌های هوایی (برگ و ساقه) و زیر زمینی (ریشه) گیاه نیشکر نمونه‌گیری صورت گرفت و میزان کربن هر بخش به صورت جداگانه تعیین شدند. نتایج نشان داد که کربن ذخیره شده در بخش بالای سطح خاک (برگ و ساقه به میزان ۱۲۹۲ $kg\ ha^{-1}$) به صورت معنی داری ($p \leq 0.05$) بیشتر از اندام‌های زیرزمینی (ریشه به میزان ۶۵۵ $kg\ ha^{-1}$) می‌باشد. کل کربن ترسیب شده در خاک (به میزان ۱۹۸۷/۳ $kg\ ha^{-1}$) با میزان کربن ترسیب شده در کل اندام‌های گیاهی (به میزان ۱۹۴۷ $kg\ ha^{-1}$) اختلاف معنی‌داری نداشت. علاوه بر این، همبستگی مثبت و معنی‌داری بین کربن آلی و میزان رس خاک مشاهده شد. برآوردها نشان داد که مقدار کربن ترسیب شده در گیاه و خاک مزارع نیشکر خوزستان ۳۹۳۴/۵ $kg\ ha^{-1}$ است که معادل ۱۴۴۳۹/۶ $kg\ ha^{-1}$ دی اکسید کربن جذب شده از اتمسفر است. به طور کلی، نتایج نشان داد در سیستم کشت راتونینگ، کل کربن ترسیب شده در مرحله راتون ۱ بیشترین میزان را دارد. در نتیجه کشت نیشکر در جنوب غرب ایران می تواند به عنوان حوضچه‌ای مهم برای ذخیره کربن عمل کرده و در نتیجه موجب کاهش اثرات تغییرات اقلیمی گردد. به نظر می‌رسد که ایجاد تغییر در سامانه فعلی برداشت محصول نیشکر که بر مبنای سوزانیدن بقایای گیاهی در مزرعه است و حرکت به سوی مدیریت پایدار با هدف حفظ بقایای گیاهی، بتواند توانایی ترسیب کربن این مزارع را افزایش دهد.