DOI: 10.17707/AgricultForest.63.4.17

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MODELING OF SOIL CARBON STORAGE CAPACITY USING FARM MANAGEMENT FACTORS IN DRYLANDS

SUMMARY

The Carbon Storage Capacity (CSC) of land ecosystems is considered as the criteria for dry land sustainability assessment through analyzing of its management factors. We studied the commonly used management systems and their affected factors to model soil carbon storage in Sarfirooz-abad watershed, Kermanshah province, IRAN. GIS layers of slope degree, slope direction and elevation created, combined and used as the homogeneous map units. Three field management systems of tillage, crop rotation and residual management were defined and their relevant indicators were quantified. The systematic random method was used for soil sampling and 95 composite soil samples were taken from 0-30cm soil depth. In the laboratory, bulk density, texture and organic carbon content of soils was determined and soil organic carbon storage stocks was calculated. To estimate and model the carbon storage capacity and factors affecting, it was studied by stepwise regression, factor analysis and clustering. Results showed that using cluster analysis by seven variables of 15 variables has the significant relation with CSC with a correlation coefficient of 0.724 including plow index, cereals in crop rotation, stubble burning, animal fertilizer, crop rotation, winter fallow and plow direction. The cluster model efficiency of 0.46 was obtained that could predict about 52% of the CSC variability. The crop rotation and tillage were the variables of precise agricultural systems management that is undoubtedly important in CSC of dry lands.

Keywords: cluster analyzing, crop rotation, tillage, Organic carbon, crop residue.

INTRODUCTION

Soils as a part of terrestrial ecosystems contain the largest stock of organic carbon. Sustainable management of soil and in particular soil organic carbon (SOC) that was supported plant productivity (Hoyle *et al*. 2011). Soils hold approximately 75% of the C stored on land and thus plays a large role in the global C cycle (Swift, 2001). Soils of the semi-arid and arid areas constitute a

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Notes: The authors declare that they have no conflicts of interest. Authorship Form signed online.

third of the global land area and are used for agricultural production (Harrison and Pearce 2000). Dry land in arid and arid areas was characterized by a low ratio of mean annual precipitation to potential evapo-transpiration and cover about 41 % of the surface of the Earth (Lal, 2004). The soils of these areas have an inherent low stock of organic carbon (C) due to climatic limitations. Soil carbon in dry land areas is of crucial importance to maintain soil quality and productivity. Soil mismanagement has led to a significant loss of carbon in these areas (Plaza-Bonilla1 et al. 2015). Agronomic choices such as crop or pasture selection, fertilizer application rates, net organic matter removal (e.g. burning), management of the soil (e.g. tillage practices), and removal of soil constraints to plant growth (e.g. liming to increase soil pH) alter plant biomass production, contributing to whether or not the actual SOC storage is as high as the attainable SOC capacity (Hoyle *et al*. 2011). The data on crop management and land-use could well be used to determine carbon storage capacity (Sayyadian et al., 2007). Crop management practices providing opportunities to reduce or increase the concentration of atmospheric carbon dioxide which store additional carbon through vegetation biomass and soil organic matter. Increasing organic matter in the soil can increase soil fertility, porosity, permeability and soil and water conservation (Dadgar, 2012). Conservation agriculture can affect the quantity of soil organic carbon by relying on management elements such as conservation tillage, residue management and crop rotation systems effectively (Parvizi, 2010). The most important determining factor for the organic carbon variability that can be controlled is farm management practices. Some of those include the change of forest and grassland to agriculture, use of equipment and intensity of tillage, fallow and crop rotation, crop residue management, use of green fertilizers and manure (Maia et al., 2010). Results of Franzluebbers (2010) showed soil organic carbon storage can be relatively high by conservation tillage. Organic carbon storage in soils creates a nutrient-rich environment for plant propagation. Conservation tillage, plant residue and animal manure on rangelands are the effective methods to increase soil organic carbon storage. Lopez et al (2011) conducted that no-till farming can be recommended as an alternative to conventional traditional tillage farming to increase organic carbon of the rainfed grain-producing areas soils. No-till system can also cause an increase of 20% of soil organic carbon storage compared to the traditional tillage system. Brown et al. (2012) found soil organic carbon change placed at the soil depth of 0-30 cm and introduced the soil depth of less than 30 cm to identify the impact of management on the surface and subsurface soil organic carbon. The Sombrero et al (2012) conducted that lands with minimal or no agricultural practices can enhance soil structure and increase the carbon storage in agricultural soils. The impact of these methods depends on soil and crop type, and farm management system. The dynamics of soil organic carbon reserves were studied by Yu et al. (2012) that was found soil organic carbon stocks on the beach, wetlands, agricultural lands and saline lands that were most affected by the human activities, can vary greatly. The results showed that human activities is a key factor for change and storage of the soil organic carbon. The tillage system and crop residue management is required for crop production and maintaining soil fertility. In this regard, Hou et al. (2012) assessed the various effects of crop residue management and tillage on soil organic carbon and concluded that the conservation tillage is suitable method for maintenance of soil fertility and crop productivity through crop residue increasing. Results of Blanco- Canqui (2013) showed potential ways to compensate for the loss of soil organic carbon through the plant residue removal and lead to increase the soil organic carbon storage by crop management, tillage, fertilizer and compost. Given the importance of carbon storage in the soil, most studies have been done on a global level limited to compare the effects of one or two management action focused on carbon storage capacity. Also, a little research was conducted on methods of quantitative analysis and an effective way to evaluate and modeled appropriate field management factors to estimate soil organic carbon. Therefore, a comprehensive study on the status of management actions that govern the land areas and in real terms is not addressed. Therefore, the aim of this study was to identify management factors and prioritize effects of these factors for the quantity of soil organic carbon storage in dry farming areas at the traditional field management condition.

MATERIALS AND METHODS

Study Area

The study area, Sarfirooz-abad catchment, with surface area of 14000 ha is located in Kermanshah, IRAN. The geographic coordinates are 47° 04' 25" to 47° 22' 18" E and from 34° 00' 38" to 34° 09' 31" N (figure 1).

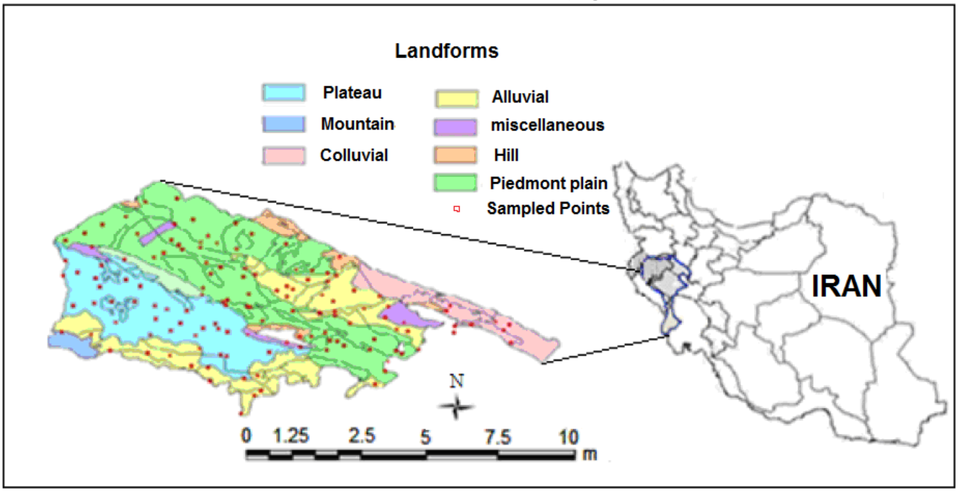

Figure 1. Location of study area (sar-firooz-abad catchment)

The average elevation is 1666 meters above sea level, mean annual temperature 8.86 ° C and mean annual rainfall 590 mm. Slope is mainly 0-5% and altitude ranges from 1500- 1800 m above sea level. The soils classified as

Inceptisols (Typic Calcixerepts, Loamy, mixed, mesic) according to the USDA Soil Taxonomy lies on Piedmont plain and Plateau. Conventional crop rotation in area is: winter fallow, Pease, Wheat and Barley planted rainfed.

Research Methodology

According to the agricultural land management practices in the study area (tillage, crop rotation and crop residue management) that could have a decisive effect on the amount of soil organic carbon storage, 15 single or combined variables based on their nature, extent and interactions identified as table 1.

Table 1. Main field management groups and related variables

	Management practices	Variables
1	Crop rotation	Farm size
2		Fertilization
3		Legume in rotation
4		Cereals in rotation
5		Crop rotation
6	Crop Residue	Pasture feeding
7		Hay harvesting
8		Hay burning
9		Livestock density
10		Residual management
11	Tillage	Soil erosion
12		Plow index
13		Mechanization index
14		Plow direction
15		tillage

With respect to the 3 management systems, the study area was delineated to 10*10 meters quadrates. The systematic random sampling (Yu et al., 2012) was performed in each quadrate. Soil samples from the 4 corners of the quadrates and their center were taken from depth of 0-30 cm (Stöckle et al, 2012) and mixed as a composite sample. Totally 95 composite soil samples are placed into the plastic bags and transferred to the laboratory. In the laboratory samples air dried, crushed lumps, separated the roots, rock and other impurities and passed from the sieve 0.5 and 2 mm (Mesh 20). Soil bulk density (gr/cm3) was measured by Clod method and soil organic carbon by Walkley-Black method (Black et al, 1965). The amount of soil carbon storage (ton/ha) calculated as relation 1 (Nieto et al., 2013).

$$CS = 10000 * SOC\% * Bd * d \qquad (1)$$

Where, CS: Carbon storage (ton/ha), SOC: Soil organic carbon (%), Bd: bulk density (ton/m3), D: Soil sampling depth (m)

Descriptive statistics of the data including average values, maximum, minimum, and standard deviation were calculated. Relationships between management factors and soil carbon storage were investigated using the Pearson correlation method. To remove of the variables that had not a significant effect on the soil carbon storage, stepwise regression was applied. The investigated management factors were soil erosion, farm size, fertilizing manure, legumes and cereals in rotation sequence, winter fallow, crop rotation pattern, animal feeding, hay harvesting and burning, livestock density, residue management, mechanization energy index, plow direction and tillage. The multivariate regression, factor analysis and cluster methods were used to evaluate the effect of the management factors on the soil carbon storage and its estimation modeling

RESULTS AND DISCUSSION

Summary of statistical indicators of the farm management and soil factors are as table 2.

Table 2. Some statistical indicators of the soil organic carbon and related management variables

	Variable	Min	Max	Average	Standard deviation
1	CS (t ha $^{-1)}$	9.65	75.40	31.196	12.490
2	Er.	0.00	3.00	0.801	0.927
3	O h (ha)	0.40	4.00	1.716	0.908
4	Mn.	0.00	1.00	0.134	0.342
5	leg.F	0.00	1.00	0.411	0.173
6	Cer.F	0.00	1.00	0.547	0.192
7	Fw	0.00	1.00	0.702	0.458
8	R.Scn.	1.00	7.00	4.411	1.612
9	Pas.	0.00	1.00	0.148	0.357
10	SH	0.00	70.00	41.631	14.693
11	Burn.	0.00	1.00	0.546	0.499
12	D.dens.	0.35	6.40	1.564	1.358
13	S.Scn.	1.00	9.00	6.721	2.098
14	Energy	0.00	2240.00	1440.255	448.630
15	T_{index}	0.00	1.00	0.759	0.250
16	Pl.dir.	0.00	1.00	0.439	0.498
17	Till.Scn.	1.00	6.00	2.546	1.523

CS: carbon storage (t/ha), Er: soil erosion, O (h): farm size, Mn.: livestock Fertilization, Leg.F: legume in crop rotation, Cer.F: cereals in crop rotation , Fw: Winter fallow, R.Scn.: crop rotation pattern, Pas: animal feeding, SH: residue removal, Burn: stubble burning, D.dens: livestock density, S.Scn.: Residue Management, Energy: mechanization Energy index (MJ/ha/y), Tindex: tillage index , P.dir.: plow direction, Till.Scn: tillage.

According to the table 2 average stock of soil organic carbon stored per unit area is about 31.196 ton/ha. Average soil erosion at the sampling points was less than one. However, in most parts of the catchment, the surface crust formation is evident at the farms. Plant residue removal at the sampling sites varies between 0 to 70% with a weighted average of 40%. Calculated linear correlation coefficients between management agents and soil organic carbon are shown in Table 3.

Table 3. Correlation matrix of farm management variables

	CS(t ha $^{-1)}$	Er.	O (h)	Mn.	leg.F	Cer.F	Fw	R.Scn.	Pas.
CS (t ha $^{-1)}$	1.000	-0.105	-0.182	0.424	0.381	-0.549	0.169	-0.436	0.171
Er.		1.000	-0.365	-0.253	0.057	0.127	0.046	0.108	-0.016
O (h)			1.000	0.051	-0.170	0.239	-0.030	0.063	-0.158
Mn.				1.000	0.169	-0.297	-0.062	-0.635	0.182
leg.F					1.000	-0.493	0.453	-0.546	-0.042
Cer.F						1.000	-0.157	0.381	-0.231
Fw							1.000	-0.657	-0.122
R.Scn.								1.000	-0.055
Pas.									1.000
SH									
Burn.									
D.dens.									
S.Scn.									
Energy									
T_{index}									
Pl.dir.									
Till.Scn.									

	SH	Burn.	D.dens.	S.Scn.	Energy	T_{index}	Pl.dir.	Till.Scn.
CS (t ha $^{-1)}$	-0.260	0.360	0.081	-0.424	-0.507	-0.580	-0.181	0.454
Er.	0.223	0.073	-0.285	0.083	-0.029	0.071	-0.243	0.180
O (h)	-0.037	-0.185	0.051	0.174	0.189	0.179	0.226	-0.301
Mn.	-0.360	-0.068	0.127	-0.293	-0.352	-0.354	0.231	0.270
leg.F	0.117	0.224	0.014	-0.219	-0.261	0.318	-0.210	0.278
Cer.F	0.373	-0.264	-0.080	0.511	0.723	0.750	0.071	-0.590
Fw	-0.001	0.156	-0.118	0.055	0.023	0.065	-0.114	-0.090
R.Scn.	0.193	-0.142	-0.034	0.248	0.343	0.322	-0.043	-0.220
Pas.	-0.343	0.011	-0.064	-0.381	-0.379	-0.340	0.104	0.218
SH	1.000	-0.180	-0.088	0.496	0.392	0.425	-0.099	-0.259
Burn.		1.000	-0.076	-0.594	-0.269	-0.372	-0.223	0.373
D.dens.			1.000	-0.096	-0.038	-0.096	0.064	-0.083
S.Scn.				1.000	0.533	0.661	0.065	-0.545
Energy					1.000	0.885	-0.054	-0.792
T_{index}						1.000	039/0	-0.755
Pl.dir.							1.000	-0.159
								1.000

As table 3, there are a significant and negative relation between soil carbon storage with the farm size and plow direction at (α=5%). The relation between soil carbon storage with the Cereals in crop rotation, crop rotation pattern, residue removal, residue management, energy index and plowing index were significant and negative, and with the fertilization, legume in crop rotation, stubble burning and tillage there were a significant and positive relationship at the level (α=1%).

To find out the most significant and effective factors on the soil organic carbon storage the following steps were employed.

Stepwise regression

Results of Stepwise regression application to predict carbon storage (table 3) showed that in the first step only the factor of cereals in crop rotation has a significant relation (R^2=0.34) with soil carbon storage. In the later step, crop rotation was added to the first model and the correlation coefficient increased to 0.41. In the third and fourth steps by adding winter fallow and stubble burning the correlation coefficients increased to 0.45 and 0.49 respectively. The final model was obtained by adding the factor of plow direction that could explain 0.52% of the soil carbon storage variety with 5 factors (equation 2).

$$CS = 5.91 - 0.298CerF - 0.051R.Scn - 0.108Fw + 0.064Burn - 0.044P.dir \quad (2)$$

Where:

CS: Organic carbon storage, *Cer.F*: Cereals in crop rotation, *R.Scn*: Crop rotation, *Fw*: Winter fallow, *Burn*: Stubble burning and *P.dir*: plow direction.

Table 4. Stepwise regression modeling of the soil carbon storage

Stepwise regression procedures	**Factors**	**R**	**R^2**
1	Cer.F	0.580	0.337
2	Cer.F + R.SCN	0.642	0.412
3	Cer.F + R.SCN + Fw	0.667	0.446
4	Cer.F + R.SCN + Fw + Burn	0.702	0.493
5	Cer.F + R.SCN + Fw + Burn + P.dir	0.714	0.517

Factor analysis

This model was used to more data reduction and limiting number of factors that could explain the most primary variables. Figure 2 shows changes of the specific value (the value of the total variance estimated by a special agent) has descending trend. According to the figure 2, five axes can be as important issues that have the most significant role to explain the variance of the data with the Eigen-value above one and explain about 71% of the variability.

According to the table 4, the first axis consists of cereals in crop rotation, the energy and tillage index as effective variables. The second axis includes the crop rotation, winter fallow and legumes in crop rotation. The third axis involves the residues removal, animal feeding and fertilization. Axis fourth consists of farm size, livestock density and finally axis fifth involves residue management and burning stubble.

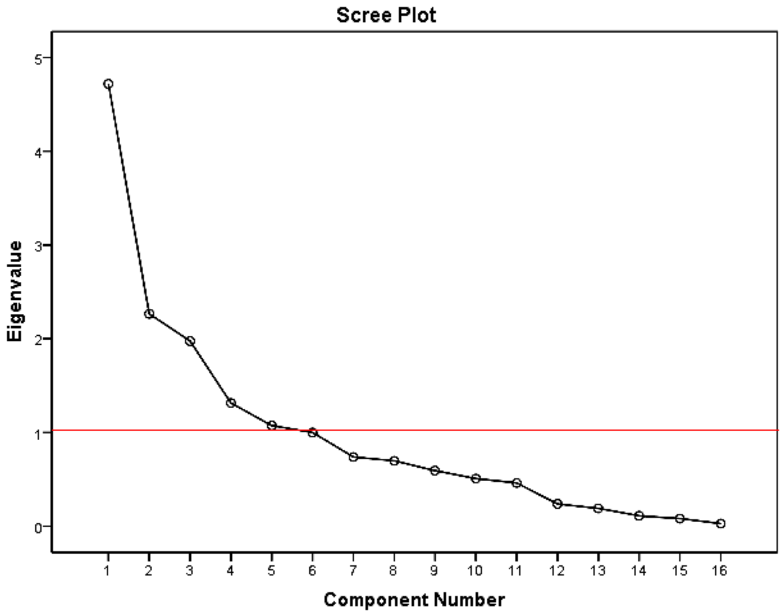

Figure 2. Number of distinct aspects of variables based on hidden roots

Table 4. Factor analysis of management variables

variables	axes				
	1	2	3	4	5
Er	0.009	-0.069	0.093	0.421	0.056
Oh	0.332	-0.034	-0.042	-0.630	-0.035
Mn	-0.153	0.233	0.182	-0.141	0.263
Leg.F	-0.369	0.738	0.191	0.111	-0.001
Cer.F	0.764	**-0.878**	0.163	0.041	0.103
Fw	0.174	0.355	0.008	0.071	-0.117
R.Scn	0.237	-0.840	**-0.757**	0.106	0.027
Pas.	-0.280	-0.146	-0.683	0.131	-0.034
SH	0.272	0.007	0.656	0.283	0.339
Burn.	-0.242	0.125	0.124	0.105	0.262
S.Scn	0.571	-0.017	0.237	0.077	0.646
Energy	0.858	-0.094	0.277	-0.052	0.096
Tindex	**-0.872**	-0.086	0.216	0.032	0.238
P.dir	0.054	-0.093	-0.327	**-0.866**	-0.437
T.Scn	-0.844	--0.013	-0.038	0.217	-0.170
D.dens	-0.355	-0.105	0.347	0.565	0.190

Based on the figure 2 and Table 4, preliminary variables of each axis applied in the regression model with four variables could explain about 48% of the carbon storage variation (equation 3). These four variables are prioritized as tillage index, cereals in crop rotation, rotation pattern and plow direction with correlation coefficient of 0.697.

$$CS = 5.864 - 0.225 Tindex - 0.153 Cer.F - 0.029 R.Scn - 0.043 P.dir \quad (3)$$

Where:

CS: Organic carbon storage, *Tindex*: Tillage index, *Cer.F*: Cereals in crop rotation, *R.Scn*: Crop rotation *P.dir*. Plow direction.

Cluster analysis

Cluster Analysis was used after factor analysis at specified homogenous levels and the factors that have more coordination and assimilation in clusters categories and thus should be employed after continuation of factor analysis. The results of cluster analysis are shown in Figure 3 that involves a summary of the similarities of the variables.

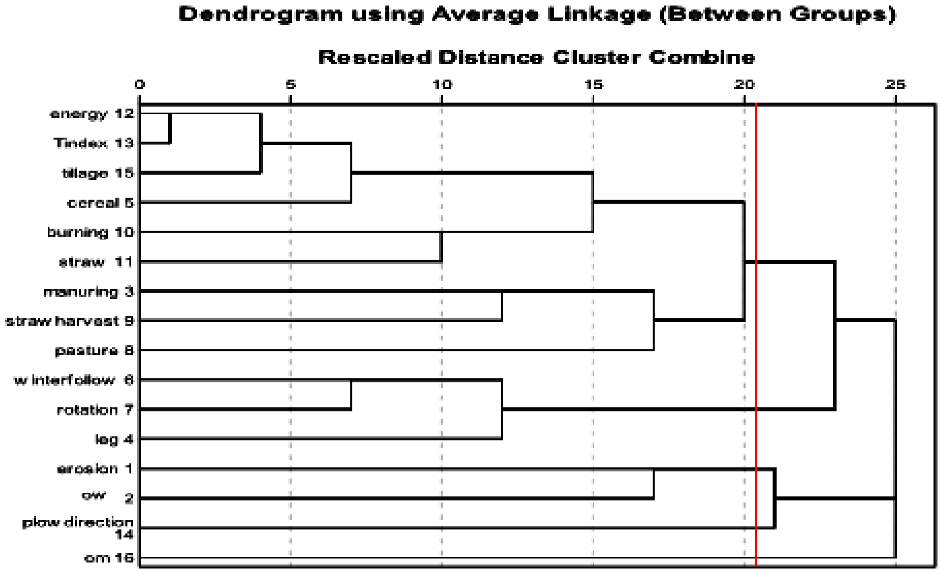

Figure 3. The cluster dendrogram for class variables of management

According to the dendrogram obtained, evaluated indicators can be classified into 5 clusters. The first cluster from below includes farm size, the second cluster includes plow direction and the third cluster involves fertilizing and erosion. The forth cluster involves rotation and winter fallow, and remained variables placed into the fifth cluster. So, applied multivariate model could explain about 52% of the variability of carbon storage by 7 variables.

$$\begin{aligned} CS = 5.863 - 0.11 Tindex - 0.19 Cer.F + 0.06 Burn \\ + 0.005 AM - 0.04 RScn - 0.07 Fw - 0.04 Pdir \end{aligned} \quad (4)$$

Where:

CS: Organic carbon storage, *Tindex*: Tillage index, *Cer.F*: Cereals in crop rotation, *Burn*: Stubble burning, *AM*: Animal Manure, *R.Scn:* . Crop rotation, *Fw*: Winter fallow and *P.dir*: Plow direction.

Model evaluation

In Table 5 the results of the stepwise were showed that the step-by-step regression can estimate soil carbon storage by limiting the input variables with an average error of about 2.16%. The model efficiency calculated about 0.45.

Table 5. Criteria evaluated three models

Model	R	R^2	% RMSE	MBE	EF
Stepwise	0.714	0.517	2.160	0.005	0.448
Factor analysis	0.697	0.485	2.162	0.004	0.447
Cluster analysis	0.724	0.524	2.137	0.016	0.460

Results of the factor analysis showed that the average estimation error was about 2.16%. Efficiency of the model implies that 44% of the variation in the observed values can be described by the model. Evaluation of the cluster analysis showed that the MBE of the model was about 0.016 and the average estimation error of the linear model was about 2.14%. The efficiency coefficient of the obtained model implies that 46% of the variation in the observed values can be described with a correlation coefficient of 0.724.

Results indicated that there are a significant correlation between carbon storage and crop rotation pattern variables and its components like sequences of crops in rotation, animal manure, crop rotation pattern, winter fallow, and tillage component like plowing index and plow direction are effective more than others. Carbon storage has a significant correlation with residue removal and its component the stubble burning. This finding is according to the Blanco- Canqui et al (2009) results. Residue removal is more effective on reducing soil organic carbon. It can also point out to the results of Huang and colleagues (2013) that showed excessive removal of crop residue reduce soil organic carbon storage. The Blanco- Canqui (2013) showed that the management practices including tillage and animal fertilizer were corresponded with the soil organic carbon storage increasing.

Sombrero and et al (2012) showed crop rotation has not a significant effect on the amount of soil organic carbon. In addition, the lands with the territory of the legume residues returned to the soil, has higher organic carbon. Huang et al (2013) conducted that soil carbon stocks in the 0-10 cm of soil depth has not a significant difference with stubble burning and residue removal at the level of 5% because stubble burning decreases of organic residues and residue removal leads to biomass and soil respiration reduction.

The results of this study have indicated that the use of cluster analysis for the projected carbon storage (Breuer, 2012) using the farm management variables, improve the ability to predict multivariate linear model. Blanco-Canqui and et al (2009) reported that soil organic carbon storage linearly decreased by harvesting corn residue regardless of the soil tillage and farming system. Almagro et al (2013) has also used linear regression and stepwise model in a Mediterranean ecosystem to determine the effect of vegetation type on carbon storage.

Our results showed that using cluster analysis model by insertion of 7 variables from a total of 16 variables that are prioritized as plow index, cereals in rotation, stubble burning, animal manure, rotation pattern, winter fallow and plow direction has a correlation coefficient 0.724 and explained about 52% of the of carbon storage variability. This finding corresponds with Parvizi (2010) partly due to 3 variables of tillage, stubble burning and fertilization.

The results of the cluster analysis showed that this model is low estimates at the high carbon storage levels (MBE= -0.016). The average estimation error of prediction using linear model was about 1.2%. The results of Wang et al (2009) showed that land use management and of soil type have the greatest impact on spatial variability of soil organic carbon.

Soil organic carbon storage changes in the agricultural land uses was affected mainly by management factors based on obtained Correlation coefficients. Cluster analysis of all the management variables showed that the plowing index, the sequence of cereals in rotation, stubble burning, fertilizing manure, periodic pattern, to plow the fallow winter were the most effective factors on the carbon storage changes.

According to the results of the three methods, cluster analysis has more precise estimate for carbon storage in soils. Among the factors that determine carbon storage changes in the agriculture land uses, the main contribution to belong to management factors can be soil tillage (plowing index and soil), rotation (succession of crops in rotation, animal manure, rotation pattern, fallow winter) and management of crop residue (stubble burning).

CONCLUSION

The impact and importance of various management factors on soil carbon storage is different. According to the results, the well-known effects of management on soil carbon storage variability implied that experts need to review the approach and attitude towards the sustainable utilization of land resources in agriculture land uses. Therefore, it is suggested that improved management systems of the different regions is a positive step in reducing atmospheric carbon density and thus storage of more carbon in the soil and also to precise land use management approach to sustainable agriculture and maintain soil carbon are highly recommended.

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