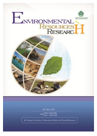

Environmental Resources Research
Vol. 3, No. 2, 2015

GUASNR

Soil Carbon Sequestration Capacity in Different Land Uses (Case Study: Award Watershed in Mazandaran Province)

Z. Jafari*[1], S. Mesri[2]

[1]MSc of Rangeland Management, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[2]M.Sc. of Soil Science, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

Received: February 2014 ; Accepted: December 2014

Abstract

One approach for reducing CO_2 and increasing global carbon storage is carbon sequestration in soils. Watersheds are important biophysical and topographic units representing diverse ecosystems. This study aims to evaluate carbon sequestration in different land uses and its economic aspect in the Award watershed in Mazandaran Province. First, the boundary of the watershed was delineated and controlled by a field survey using GPS. Then, soil samples were selected randomly, taken from a depth of 0-30 cm for each land use (i.e., protected forest, open forest, rangelands, walnut gardens, mixed walnut–apple gardens, cereal croplands and frijol farmland). In total, 21 soil samples were taken from the study area. The selected parameters for analysis were the amount of carbon sequestration and certain soil properties (bulk density and organic carbon). Statistical analysis was performed using the SPSS.16.0 software. After assessment of the homogeneity of variance, analysis of variance (ANOVA) was performed followed by Duncan test at a significance level of 5%. Results demonstrated that the different land uses had different effects on the amount of carbon sequestration. The protected forests and cereal croplands had the highest and lowest carbon sequestration values, respectively. The overall amount of carbon sequestration in this watershed was estimated to be around 743,460 ton/ha.

Keywords: Soil Carbon Sequestration, Land Uses, Watershed, Award (Mazandaran).

*Corresponding author; jafariz68@yahoo.com

1. Introduction

The growing population needs certain resources, such as water, food and land that are also limited on earth. Another issue that matters is the quality of the resources; therefore, human beings need proper conditions for a clean atmosphere and healthy food. Nowadays, the increase in fossil fuel consumption, land use changes and vegetation deterioration have led to the release of large amounts of greenhouse gases into the atmosphere (IPCC, 2001), leading to various problems such as air pollution and temperature increases - and climate change as a whole. From 1980 to 1995, the improper management of land uses has degraded around 18% of the organic carbon storage of soils (Lal, 2004). Since 75% of the carbon in semi-arid and arid ecosystems is stored in the soil, an optional approach for reducing CO_2 and improving global carbon storage is its sequestration in soils. Carbon sequestration is a procedure for absorbing extra CO_2 from the atmosphere, and one approach involves transforming it into organic matter, into aerial and underground organs of plants, especially by planting of resistant vegetation species in rangelands. There are many studies about the usefulness of corrective operations - such as protection and planting of green vegetation in rangelands - for carbon sequestration. Derner et al. (1997) compared the amount of carbon sequestration in two depths of 0-15 cm and 15-30 cm of surface soils in the two different areas of the protected and grazed rangelands. Their results indicate that the carbon sequestration in grazed areas is more than in non-grazed areas at a depth of 0-15 cm, with no statistically significant differences between the two. Moreover, Joneidi Jafari (2009) showed that grazing management has a significant influence on the capacity of soil carbon sequestration. In forested areas with species from Aceraceae and Rosaceae, and lack of invasive species in lower stands, carbon sequestration was increased by around 23% in the soil. Correspondingly, the livestock density and deforestation led to an approximately 12% decrease in soil carbon. Schuman et al. (2002) evaluated corrective management operations, such as fertilization and grazing in the United States, and found that these operations increased the level of carbon sequestration as well. Ahmadi et al. (2009) by surveying the effect of planting distance on carbon sequestration in the species Haloxylon in the south of Salt Lake, Iran, found that a large amount of the carbon is sequestered under the canopy of the plants. Ojima et al. (2000) studied the effect of croplands and rangelands on carbon storage; and concluded that the overuse of rangelands and their conversion into farmland increased the erosion and sedimentation rates, and caused a reduction in the carbon sequestration potential.

In this study, we measured the effect of management practices on carbon sequestration in soils. W aimed to provide a paradigm for proper watershed management as well.

2. Materials and methods

2.1.Study area description

The Award watershed is in the Mazandaran province, located between longitudes 53° 42' 37"E to 53° 57' 18"E, and between latitudes 36° 35' 40 N to 36° 39' 5"N. This watershed covers a total area of 9,410/74 hectares, and it is a sub-basin of the Neka River basin, which is located to the east of Mazandaran and South Galogah. The villages in the watershed include Award, Nyala, Yakhkesh, Sefid Chah, Pjym and Ramedan. According to the land morphology and landforms, this watershed is a mountainous watershed overlooking the River Neka valley. Since this watershed is a non-hydrological basin and is composed of both independent and connected units, there is no unique mainstream here. Nonetheless, the River Neka, which exists along the southern borderline of the basin, can be considered to be the mainstream – with a 1,400 metres length, it originates from the northern highlands and passes through the middle of the basin to exit from the southwest of the basin output. Based on the Embergern classification, the Award watershed has a cold Mediterranean climate, and according to De Martonne method, the area is a semi-humid climate. The average rainfall in the basin is around 459 mm per year, falling mainly in the form of rain. The average temperature in the study area reaches around 11.46 °C. The lowest temperatures occur in January, and the hottest temperatures are in July. Because of a proper spatial distribution of villages in the watershed, the products of agriculture, gardening and animal husbandry are adequate, and the highlands of the study area have relatively rich vegetation as well.

2.2.Field survey and soil sampling

In this study, using the Google Earth software, the boundary of the watershed was delineated and controlled through a field survey using GPS. The total watershed was selected as the study area and soil samples were taken randomly from a depth of 0-30 cm for each land use (i.e., protected forest, open forest, rangelands, walnut gardens, mixed walnut–apple gardens, cereal croplands and frijol farmland). Samples were obtained from seven points with three replications in each spot. Finally, 21 soil samples were collected from the study area and then transported to the laboratory. The samples were dried and put through a 2 mm sieve. To determine the bulk density of the soil, an aggregate series of each horizon was taken, and the bulk density of each sample was determined using the aggregate and the paraffin methods of Black and Hertage (1986). The organic carbon of the soil was measured using oxidation of potassium dichromate (Nelson, 1982). Via this method, the soil organic carbon was calculated based on the organic carbon percentage (%OC).

To estimate the content of the carbon and its total mass (weight) in the soil, rather than its percentage, we used carbon content (g) in the soil unit (kg), as shown in Equation 1.

$$OC_{(grC/Kg\ soil)} = \%OC \times 10 \quad (1)$$

Where OC is the amount of soil organic carbon in one gram of carbon per kg of soil, and OC% represents the organic carbon percentage of the soil. Having a weight of organic carbon per soil weight unit (gr C/Kg soil), the soil bulk density and its depth, the organic carbon per unit area is calculated by Equation 2 (Pimental, 1997).

$$Sc = e \times Bd \times OC_{(grC/Kg\ soil)} \times 10 \quad (2)$$

Where Sc indicates the amount of carbon in the soil in ton/ha at a certain depth, and e is the soil depth (meter). OC represents the organic carbon mass for a gram of carbon per a kilogram of soil, and Bd denotes the soil bulk density for a gram per cubic centimetre.

The statistical analysis of the data was performed using the SPSS 16.0 software. Initially, the normality of the data was checked, including the existence of outliers. After the homogeneity of variance test, in order to test the null hypothesis of equal averages in seven land uses, a one way analysis of variance (ANOVA), was carried out and then in order to compare their means; Tukey's test was used at a 5% significance level.

3. Results

3.1. The organic carbon of soil

Organic material is an important indicator of soil fertility, which is key to improving the bio-physicochemical characteristics of the soil. The organic matter has been considered as a main indicator of soil quality (Reeves, 1997; Lal, 1997). Carbon is stored as soil's organic matter, but its storage is affected by intensive farming and the overexploitation of land. When forest are converted to croplands, the amount of organic carbon in the soil is reduced, even though its rate is controlled by certain effective agents, such as climatic factors and the intensity of cultivation.

The results (Table 1) indicated that the type of land cover has an influence on the soil's organic carbon as well as the soil organic matter as a whole. The statistics showed statistically significant differences for seven land uses (p value <0.05). The most important factor in the reduction rate of the organic matter in the soil is tillage, which increases the rate of decomposition of the organic matter. Aguilar et al. (1988) indicated that the tillage made the low layers of the soil with lower organic matter mix with the topsoil with a higher organic matter; and as a result, the organic carbon of the topsoil is reduced. Lal (1999) argued that the severe, intensive use of the land reduces the surface cover amount and, therefore, decreases the quality and quantity of the organic carbon in the soil. Consequently, the soil's organic matter is an indicator of the healthiness and quality of the soil, and management and corrective activities (Lal, 1999; Farquharson *et al.*, 2003) heavily influence it.

Table 1. Analysis of variance (ANOVA) for carbon sequestration in different Land uses

Variable Type	Sum of squares	df	Mean square	Sign.	F
Variance between groups	70.034	6	11.672	0.002*	6.325
Variance within groups	25.838	14	1.846		
Variance total	95.872	20			

*Significant difference at a 5% level; df represents the degree of freedom.

3.2. The carbon in the soil

The estimated results of carbon sequestration in an area unit (ha) for seven land uses are shown in Table 2. Each land use has a different effect on the carbon sequestration rate, and their differences are statistically significant at the 0.05 level. As such, the maximum amount of carbon sequestration per ha was observed in the protected forests, and the lowest in the cereal farmland (Figure1).

Table 2. Variations of soil properties in the depth (0-30 cm) in Award watershed

Land Use	Carbon Sequestration (ton C/ ha)	Bulk Density (gr/cm^3)	Organic Carbon (grC/kg soil)	Organic Carbon (%)
Protected Forest	257100[a]	10[a]	85.7[a]	8.57[a]
Open Forest	82500[c]	10[a]	27.5[b]	2.75[b]
Walnut–Apple Garden	75600[c]	7[a]	36[b]	3.60[b]
Walnut Garden	91200[c]	8[a]	38[b]	3.80[b]
Rangeland	112080[c]	8[a]	46.7[b]	4.67[b]
Frijol Farmland	74340[c]	7[a]	35.4[b]	3.54[b]
Cereal Cropland	50640[b]	4[a]	42.2[b]	4.22[b]

* Similar letters indicate no significant difference at the 5% level.

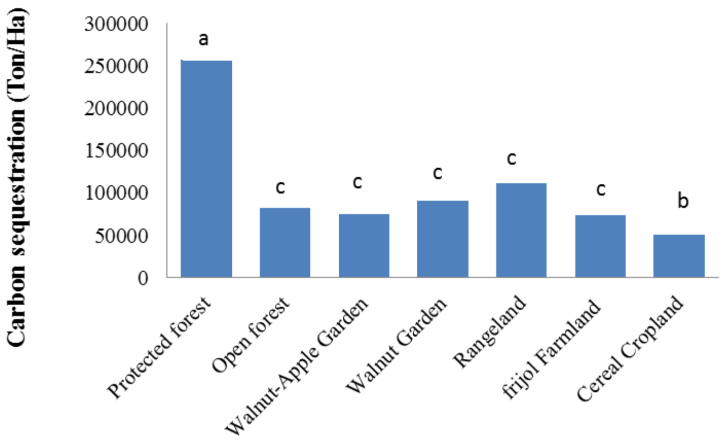

Figure 1. Variations of the carbon sequestration (ton /ha) in the Award watershed

4. Discussion

The seasonal Physical – chemical parameters in Aras dam is shown in Table 1.

Table 1. Seasonal Physical – chemical parameters in Aras dam

Season / Parameter	Aras dam				
	Spring	Summer	Fall	Winter	Mean
Air Temp(°C)	27	30	15	7	20
Water Temp(°C)	20	26	14	6	16.5
PH	7.5	8.5	8.5	8.8	8.3
Do (ppm)	9.4	9.8	10.7	15.2	11.3
TN (ppm)	1.85	1.87	3.39	4.86	2.99
TP (ppm)	0.1	0.074	0.09	0.068	0.082
Ca (ppm)	25.3	30.9	54.3	54.5	41.2
Hardness (ppm)	293	300	426	393	353
Chl-a (μgl^{-1})	26.2	17	19.8	24.2	21.8

The first females containing eggs were observed in late December with water temperature 4°C and then in January at 3°C all females copulated and contained eggs below abdomen. In mid May, when the water temperature was 18° C, the first females containing miniatures were observed. With increasing water temperature to 20°C in mid-June, all females contained miniatures and some had released their miniatures. In mid June and with increasing water temperature to 20°C, females released miniatures. Therefore, the propagation time of *A. leptodactylus* in Aras reservoir were determined from early December to mid June (nearly 6 months) and capture period were determined from early June to late November. Males molting began in late April, when water temperature reached 16°C, and finished in late

May. The second molting of males took place in mid September when the water temperature reached 18°C. Molting of females was simultaneous to the second molting of males and took place in mid September at 18° C water temperature. A comparison was made between W.F. and A.F. in the present and other studies.

Table 2. Comparison between W.F and A.F in the present study and some other studies

Reference	Location	Working fecundity	Absolute fecundity
Present study	Aras reservoir (Iran)	246	286
Karimpour and Hosseinpour(1997)	Aras reservoir (Iran)	322	420
Karimpour et al. (1991)	Anzali lagoon (Iran)	249	---
Karimpour et al. (2003)	Aras reservoir (Iran)	211	358
Rumyanteseva (1989)	Caspean sea (Russia)	---	276
Abdolmaleki (2009)	Shorabil Lake (Iran)	311	---
Koksal (1979)	Europe	183	210
Stypinskaya (1972)	Lake Dlnzek (Poland)	---	374

The mean total length and total weight of captured *A. leptodactylus* from Aras reservoir in 2008 were reported as 106.43±7.94mm and 35.81±10.86g, respectively (Mohsenpour Azari *et al.,* 2011). There was a significant difference between W.F of the studies presented in Table 2 ($P<0.05$). Also, a significant variation was observed between A.F of the present study with other studies ($P< 0.01$, Table 2). Among these studies, the results of our study showed an average level of fecundity which shows a relatively suitable condition of crayfish population reproduction in Aras reservoir.

The mean and maximum total length and weight of *Astacus leptodactylus* from Aras reservoir in 1996 had been reported as 120.51±0.69 mm, 186 mm and 54.68± 1.53 g and 239.4g, respectively (Karimpour and Hosseinpour, 1997). In Shorabil lake of Ardabil the mean total length of freshwater crayfish had been reported as 133.8±14.6 mm and their mean weight were reported as 82.5±32.4 g and maximum length and weight were 196mm and 328 g, respectively (Abdolmaleki *et al.,* 2009).

There was no significant difference in the length of W.F between the present study and other studies (Table 3). Though, there was a significant variation in the length of A.F between present study and other studies ($P<0.05$). This shows that the length of W.F in Aras crayfish population in the present study was lower than that of other studies. Reduced length of Aras crayfish population may be attributed to overfishing in the few last seasons. Maximum total length of Turkish freshwater crayfish has been reported as 145 mm (Koksal, 1988). Also, in Egirdir Lake of Turkey, the average range of captured freshwater crayfish has been reported as 40 to 150 mm (Balik *et al.,* 2005). Maximum length of freshwater crayfish from Anzali lagoon has been reported as 135 mm (Karimpour *et al.,* 1991). As noted, freshwater crayfish from Shorabil Lake of Ardabil had larger size compared to other reported lakes, perhaps due to lack of large capture operations.

Table 3. Comparison between length of W.F and A.F in the present study and some other studies

Reference	Location	Length in W.F	Length in A.F
Present study	Aras reservoir (Iran)	113	101
Karimpour and Hosseinpour (1997)	Aras reservoir (Iran)	---	122
Karimpour et al (2003)	Aras reservoir (Iran)	118	120
Koksal (1979)	Europe	120	---
Rumyanteseva (1989)	Caspean sea (Russia)	---	110
Stypinskaya (1972)	Lake Dlnzek (Poland)	---	115

The best and most common management method to prevent over capture of *A. leptodactylus,* has been reported as increasing minimum size and restriction of capture season (Karimpour *et al.,* 2003). If over capture of small sized *A. leptodactylus* took place or capture season was not considered, the mean size of captured freshwater Cray fish could have decreased and even reached the pre adult size. In such cases, the stocking would be severely at risk (Momot, 1985). Unfortunately, during last decades, the stocking rate of *A. leptodactylus* in Aras reservoir has been severely decreased that could be due to over capture of stocks, out of season capture, unsuitable ecological condition and recent droughts.

The most important factor for estimating the production potential of a population is determination of its fecundity. *Astacus leptodactylus* enjoys a high fecundity and its working fecundity fluctuates between 200 to 400 eggs (Koksal, 1988). The mean absolute fecundity and total length of *Astacus leptodactylus* in 1996 in Aras reservoir were 420.41±42.51 eggs and 121.93±4.27mm (Karimpour and Hosseinpour, 1997). The mean absolute fecundity of *Astacus leptodactylus* from Aras reservoir in 2002 were reported as 358.61±12.92 eggs with maximum and minimum of 599 and 133 eggs and the mean total lengths of 119.40 ± 1.55 mm (Karimpour *et al.*, 2003). Stypinskaya (1972) in Diuzak Lake of Poland determined the range of the absolute fecundity of freshwater crayfish with total length of 95-135 mm as 210 to 410 eggs while mean absolute fecundity of freshwater crayfish in Mazurian Lake in the same country was 374 eggs. In Egridir Lake of Turkey, the mean absolute fecundity was 210.08±8.73 eggs. Also, the smallest female with total length of 89 mm had 148 eggs and the largest female with total length of 132mm had 474 eggs (Koksal, 1979). In Turkmenistan waters, absolute fecundity of freshwater crayfish of the Caspian Sea was reported as 276 eggs (Rumyanteseva, 1989). The mean working fecundity in 1996 was 322.04± 29.61eggs with maximum and minimum of 786 and 112 eggs (Karimpour and Hosseinpour, 1997). The mean working fecundity in 2002, were 248.98±9.12 eggs with mean total length of females as 118.50±1.26 mm and maximum and minimum egg number of 591 and 92, respectively (Karimpour *et al.,* 2003). The mean, maximum and minimum working fecundity of Anzali freshwater crayfish were reported as 211±22, 413 and 92 eggs, respectively (Karimpour *et al.,* 1991). In Shorabil Lake of Ardabil, the mean working fecundity has been reported as 311.11±22.92 eggs (Abdolmaleki *et al.,* 2009). In Egridir Lake of Turkey, the mean absolute fecundity was 183.06± 9.05 eggs and the smallest female with total length of 90 mm had 101 eggs and the largest female with total length of 150 mm had 369 eggs under the abdomen (Koksal, 1979). The number of eggs varies in different sub-species and populations of one species (Cobb and Wang, 1985). Populations of one species of freshwater crayfish have different fecundities under different environmental and geographical conditions (Morrissy, 1976). When the population density is high in an aquatic system, its fecundity is decreased due to feeding competition (Momot and Growing, 1972). The decreased egg number or scarcity of freshwater crayfish containing eggs in one population is a reaction to nutritional deprivation in an aquatic system (Abrahamsson, 1972). Absolute and working fecundities strongly depended on the size of freshwater crayfish (Lindqvist and Lahti, 1983; Abrahamsson, 1972). The difference between absolute and working fecundity were calculated as 13% in Turkey (Koksal, 1988), 21% in Aras (Karimpour and Hosseinpour, 1997), 17.5% in Caspian freshwater crayfish of Anzali port beaches (Karimpour et al, 2003), nearly 30 % in north Caspian sea freshwater crayfish (Baradaran Naviri, 2001, Matinfar, 2007), 21% in Aras *Astacus leptodactylus* (Karimpour *et al.,* 2004) and 15% in this study, which differed from previous studies on Aras reservoir *Astacus leptodactylus*. This difference can be attributed to inability of attachment of fertilized eggs to phyllopods and or un-fertilization of eggs during passage through spermatic chamber (Abrahamsson, 1972).

4. Conclusion

Estimate of the soil carbon sequestration showed that it varies for each of the different treatments. The ANOVA test showed significant differences in the carbon sequestration amounts in the different land uses, such that the highest values occurred in the protected forest, but the lowest amount of carbon sequestration was in the cereal cropland. The variance of carbon sequestration was related to the type of management and the land use. In fact, carbon sequestration potential is influenced by plant species, locations and management practices (Mortenson and Shuman, 2002). Broadly, in the watershed of Award, forests had the highest biomass per unit area compared to other land covers. In addition, studies completed by Bordbar and Mortazavi Jahromi (2006) have shown that the biomass of forest is directly related to carbon sequestration. The protected forest has the highest rates of carbon sequestration in the watershed. Therefore, we suggest that forest ecosystems have a high capacity for carbon storage. However, rangelands in this watershed, covered by grass and bushes over the years, have been grazed extensively by domestic animals, and as such they exhibited a low degree of carbon sequestration per area unit.

The estimates in the watershed of Award indicated that this area had a potential equal to 743,460 ton/ha for carbon sequestration. Assuming that the economic value of a ton of carbon sequestration is at least $50 (Luciuk *et al.,* 2000); the total value of annual carbon sequestration might be around $37,173,000. Therefore, as regards the conscious exploitation of watersheds, the amount of carbon storage could be an indicator of output for sustainable development.

The results of this study reveal some significant differences in the amounts of organic matter in soils, but there were no significant differences in the soil bulk density after the conversion of forests into gardens and croplands. Based on these results, it was found that converting forest into other types of land use reduces the soil's organic matter and increases its bulk density. Consequently, according to this research, the forest to the south of the Caspian Sea need a timely and more attention, especially in order to protect these areas from land-use change. In addition, the low-yield lands must change to high-productivity gardening. The results here indicate that there are many lands with low yields which are cultivated, especially in steep highlands. It is recommended that these lands should be converted into productive gardens. This approach will prevent land degradation and soil erosions, and will protect the land and provides a number of benefits to the society.

References

Aguilar, R., Kelly, E.F., and Heil, R.D. 1988. Effect of cultivation on soil in northern Great Plains rangeland. Soil Science Society of America Journal. 52:1081-1085.

Ahmadi, H., Heshmati, Gh.A., Pesarkali, M., and Naseri, H.R. 2009. Effect of planting distance of *Haloxylon* species on soil carbon sequestration in (Case Study: South Salt Lake). The 4th National Congress on Range and Range Management, Karaj, Iran. 265p (In Persian)**.**

Black, G.R., and Hartge, K.H. 1986. Bulk Density. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, 2nd ed., Agronomy. 9: 363-382.

Bordbar, K., and Mortazavi Jahromi, S.M. 2006. Evaluation of carbon storage potential in forestations of Eucalyptus and Acacia in western region of Fars province. Journal of Research and Development of Natural Resources.70: 103-95.

Derner, J.D., Beriske, D.D., and Bouttonm T.W. 1997. Does grazing mediate soil carbon and nitrogen accumulation beneath C4, Perennial Grasses along an Environmental gradient? Plant and Soil. 191: 147-156.

Farquharson, R.J., Schwenke, G.D., and Mullen, J.D. 2003. Should we manage soil organic carbon in Verticals in the northern grains region of Australia? Australian Journal Exprimental. Agriculture. 43: 261-270.

IPCC. 2001. The Scientific Basis. IPCC third assessment report, Working group I, Technical Summary, Cambridge University Press, Cambridge, UK. 881 pp.

Joneidi Jafari, H. 2009. Investigating the influence of ecological factors and management on the rate of carbon sequestration (Case study: the rangeland of Semnan province). Thesis in Range Management. Faculty of the Natural Resources, Tehran University.

Lal R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma. 123: 1–22.

Lal R. 1997. Degradation and resilience of soils. Philosophical Transaction of the Royal Society London. Biological Science. 352: 997-1010.

Lal, R. 1999. Soil quality and food security: the global perspective. In: Lal, R. (Ed.), Soil Quality and Soil Erosion. Soil and Water Conservation Society and CRC Press, Boca Raton.

Luciuk, G.M., Boonneau, M.A., Boyle, D.M., and Vibery, E. 2000. Prairie rehabilitation, administration paper, Carbon sequestration additional environmental, benefits of forests in the Prairie Farm Rehabilitation Administration. 22: 191-194.

Mahmodi Taleghani, E., Zahedi Amiri, G., Adeli, E., and Sagheb Talebi, Kh. 2007. Assessment of carbon sequestration in soil layers of protected forest. Iranian J. of Forest and Spruce Research. 15(3): 241-252.

Mortenson, M., and Shuman, G.E. 2002. Carbon sequestration in rangeland inter-seeded with yellow-flowering Alfalfa (*Medicago sativa* spp. Falcata), USDA symposium on natural resource management to offset greenhouse gas emission in University of Wyoming.

Nelson, R.E.1982. Carbonate and Gypsum. In: Methods of Soil Analysis. Part II. Page, A. L. (Ed.). American Society of Agronomy, Madison, Wisconsin, USA. Agriculture. Natural Resource. 12(44): 123-134.

Ojima, D.D., Parton, W.J., Mosier, A., Morgan, J., Conant, R., and Paustian, K. 2000. Carbon storage in land under cropland and rangeland management, Advances in terrestrial ecosystem carbon inventory, measurements, and monitoring. Conference in Raleigh North Carolina.

Pimental, D. 1997. Soil erosion and agricultural productivity: The global population, food problem. Ecological perspective in science, humanities and economics. 6(3): 197-204.

Reeves D.W. 1997. The soil organic matter in maintaining soil quality in continuous cropping systems, Soil and Tillage Research. 43: 131-167.

Schuman, G.E., Janzen, H., and Herick, J.E. 2002. Soil carbon information and potential carbon sequestration by Rangelands. Environmental Pollution. 116: 391-396.