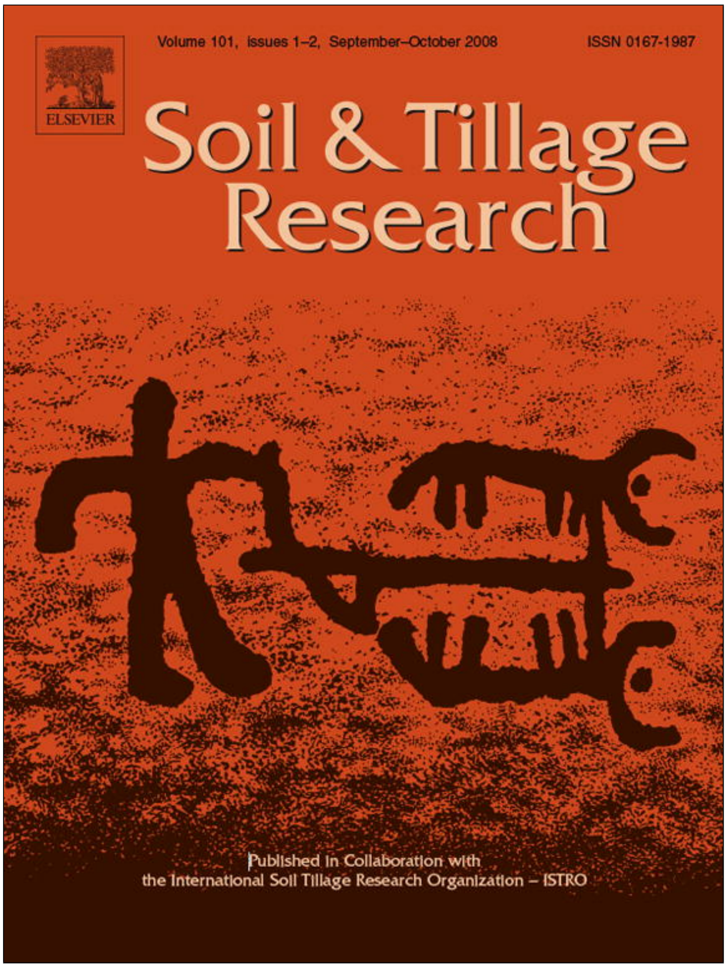
Volume 101, issues 1–2, September–October 2008
ISSN 0167-1987
ELSEVIER
Soil & Tillage Research
Published in Collaboration with
the International Soil Tillage Research Organization – ISTRO

Soil & Tillage Research 101 (2008) 57–61

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Cropping system effects on carbohydrate content and water-stable aggregates in a calcareous soil of Central Iran

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ARTICLE INFO

Article history:
Received 21 August 2006
Received in revised form 25 January 2008
Accepted 13 June 2008

Keywords:
Soil quality
Carbohydrate
Arid regions
Iran

ABSTRACT

The effect of humus, readily decomposable organic matter, and carbohydrates of a nonspecific nature on the formation of water-stable aggregates in field rotation members of a calcareous soil in central Iran, Isfahan (*fine loamy mixed thermic typic haplargid*) has been studied. The study was carried out at Lavark experimental farm in plots receiving 0 (T1), 25 (T2), 50 (T3) and 100 (T4) Mg/ha of manure for 5 years successively with a cropping rotation of wheat (*Triticum aestivum* L.)–corn (*Zea mays* L.) every year and plots under similar chemical fertilizer management but with three different cropping rotations (T5, T6 and T7) that has been the prevalent cropping systems. Three replications of soil sample in each treatment and at the depths of 0–5 and 5–15 cm were used to measure organic carbon (OC), hot-water-soluble carbohydrate, dilute acid hydrolysable carbohydrate, cold-water-soluble carbohydrate and mean weight diameter of water stable aggregates. The highest amount of carbohydrate (700 mg/kg) and aggregate stability (0.8 mm) were obtained in plots with 100 Mg/ha manure (T4). The amount of carbohydrate extracted from soil samples decreased in the order of hot water, dilute acid and cold water extracts.

Aggregate stability had a better correlation with hot water ($r = 0.74^{**}$) and dilute acid-soluble carbohydrate ($r = 0.73^{**}$) than organic carbon ($r = 0.62^{**}$) content of soil. This indicates that the carbohydrate extracted by hot water and dilute acid may be a suitable indicator for showing soil quality, particularly in relation to soil aggregation.

1. Introduction

Evaluation of land productivity and improvement or maintenance of soil quality and health is necessary to define sustainable agricultural practices (Wright. and Anderson, 2000). In this regard studying the influence of management practices on soil physico-chemical properties and plant characteristics has an important role. Evidence that soil management induced properties help plants to thrive in arid conditions has been reported for root (mycorrhizae) (Caravaca et al., 2003; Alguacil et al., 2005), increasing the supply of nutrients (Smith and Read, 1997), improving soil aggregation in eroded soils (Caravaca et al., 2002) and reducing water stress (Augé, 2001). Carbohydrates are thought to play a major role in this respect and many attempts have been made to characterize this involvement (Cheshire, 1979). No technique for directly quantifying the amount of labile organic bonding compounds in soil has been identified and no specific extraction methods, such as strong acids or bases can differentiate between total carbohydrate content and the more specific carbohydrate sub-pool that maybe involved in aggregate stability (Cheshire, 1979). Haynes and Swift (1990) suggested that hot-water-extractable carbohydrate might represent such pool. Haynes and Beare (1996) found that carbohydrate content of hot water extracts may be used as an index of soil quality, particularly in relation to soil aggregation. Haynes et al. (1991) in a short-term pasture study found that the amount of hot-water-extractable carbohydrate was changed much more rapidly than organic C. In this respect, an ongoing study of the cropping management effects on carbohydrate content and water-stable aggregates of a calcareous soil at the Isfahan University of Technology Research Station and the nearby farms has shown significant increases in yield from manure added to soil compared with no manure.

The observed differences in yield suggest that organic matter storage and dynamics have likely been affected by tillage and rotation in these systems. Efforts to conclusively explain these differences through assessment of soil physical and chemical

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doi:10.1016/j.still.2008.06.003

properties have failed, suggesting the hypothesis that soil biological processes may be responsible for the observed management induced changes. A better understanding of such systems could provide valuable insight into soil organic matter (SOM) dynamics and microbial activity under varying crop management systems. The objective of this study were (1) to evaluate changes in aggregate stability and carbohydrate fractions under different manure rates and cropping systems and (2) to assess the role of the carbohydrate fractions of a calcareous soil in aggregate stability.

2. Materials and methods

This research was conducted to investigate the effects of different cropping systems on structural characteristics and carbohydrate contents of a calcareous soil (*fine loamy mixed thermic typic haplargid*) in central Iran (Isfahan). The soil (pH 8.6, ECe = 17 dS/m, OC = 249.4 g/kg, TN = 13.06 g/kg) received 0 (T1), 25 (T2), 50 (T3) and 100 (T4) Mg/ha of manure for 5 years successively with a cropping rotation of wheat–corn every year and similar soil with identical chemical fertilizer management but three different cropping systems (T5, T6 and T7) at Lavark experimental farm (51°23′E and 32°32′N). The history of different cropping systems is presented in Table 1. The annual stubble mulches were either very low or grazed by sheep. The climate is semiarid with a 140-mm mean annual rainfall, and a mean annual temperature of 14.5 °C. A plot area of 45 m^2 was used for each treatment with irrigation method of flooding kept not less than almost 75% of FC. In July 2004 three samples from each treatment were taken from depths 0–5 cm to 5–15 cm. Soil samples were air dried and sieved prior to the analysis. Soil pH and EC (1:2.5) and calcium carbonate equivalent (CCE) were determined using the methods suggested by Soil Survey Laboratory Staff (1992). Organic carbon (OC) was determined by the wet oxidation method (Walkely and Black, 1934), and particle size distribution was determined by hydrometer method (Gee and Bauder, 1986). The results of some measured characteristics of the soil is shown in Table 1.

2.1. Carbohydrate content

The carbohydrate fraction in soil samples (<2 mm fraction) were determined in three types of soil extracts, viz. dilute-acid-soluble, hot-water-soluble and cold-water-soluble as follows:

1. One gram of soil was mixed with 10 ml of 0.25 M H_2SO_4 and shaken in a plane rotary shaker for 16 h.
2. One gram of soil was mixed with 10 ml of hot distilled water (85 °C) and heated for 2.5 h.
3. One gram of soil was mixed with 10 ml of cold (25 °C) distilled water and shaken in a plane rotary shaker for 16 h.

All three types of soil suspension were centrifuged at 3000 rpm for 30 min. After centrifugation, 2 ml of supernatant solution was used to determine carbohydrate concentration using phenol–sulfuric acid method of Dubois et al. (1956). The absorbance was read in a spectrophotometer at 490 nm. The calibration curve was obtained using glucose standard.

2.2. Water-stable aggregates and aggregate stability

The procedure described by Kamper and Rosenau (1986) was used to separate water-stable aggregates. Fifty grams of air-dried soil samples (<4 mm) were put in the topmost of a nest with five sieves of 2, 1, 0.5, 0.25 and 0.1 mm mesh size. Thereafter the nest of sieves and its contents were oscillated vertically in water for 5 min using 4 cm amplitude at the rate of one oscillation per second. After wet-sieving, the resistant soil materials on each sieve and the unstable (<0.1 mm) aggregates were quantitatively transferred into beakers, dried in oven at 50 °C for 48 h, weighed and corrected for sand content by dispersion in sodium hexametaphosphate. The mean weight diameter (MWD) was calculated with the following equation:

$$\text{MWD} = \sum_{i=1}^{n} X_i W_i$$

where X_i is the mean diameter of the ith sieve size and W_i the proportion of the total aggregates in the ith fraction.

2.3. Data analysis

A completely randomized block design was implemented with seven treatments and three replications. Analysis of variance procedure (ANOVA) for all treatments was conducted using SAS program (Release 8.02). The difference between specific pairs of mean was identified using Duncan test ($P < 0.01$).

3. Results and discussion

3.1. Changes in total organic carbon concentrations

The amounts of OC under different cropping systems were significantly different at each plot (Fig. 1). The greatest amount of OC was obtained for T4 (100 Mg/ha of manure) cropping system (4%) and the lowest quantity (1%) of OC was obtained for the T1 (no fertilizer). The amount of OC for the depth of 0–5 cm was significantly higher than 5–15 cm (Table 2). Different SOM pools, with varying stability and turnover rates, have been identified in other studies too (Angers and Dayegamiye, 1991). Soil carbohydrates, which represent from 5 to 25% of SOM, constitute a significant part of the labile pool of SOM and are mostly affected by

Table 1
Measured characteristics of the silty clay loam soil with history of different cropping systems at the Lavark research farm

Treatments[a]	pH	EC (dS/m)	CCE (%)	2000[b]	2001	2002	2003	2004
T1[b]	8.30	0.5	37	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat
T2[b]	7.62	0.95	35	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat
T3[b]	7.60	1.20	34	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat
T4[b]	7.53	1.50	33	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat	Corn–wheat
T5[c]	7.80	0.46	36	Corn	Wheat	Alfalfa	Alfalfa	Alfalfa
T6[c]	7.80	0.65	37	Wheat	Corn	Barley	Wheat	Corn
T7[c]	7.38	3.00	43	Barley	Rice	Barley	Rice	Fallow

[a] Treatments are plots annually receiving 0 (T1), 25 (T2), 50 (T3) and 100 (T4) Mg/ha of manure, and plots receiving chemical fertilizer with fallow (T5), and rotations of barely, wheat, corn (T6) and barely, rice, fallow (T7) for the last 3 years (details in Table 1).
[b] With the exception of fourth year of cropping system in T7, the plant residues in other cropping system return to the soils.
[c] N, P, K, sufficient chemical fertilizers were applied based on soil testing analysis.

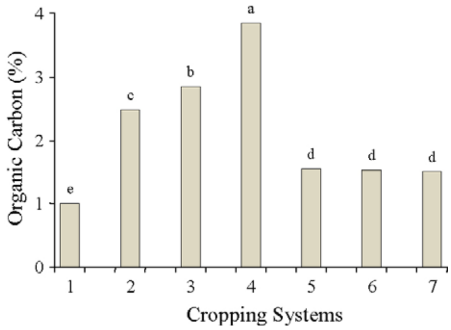

Fig. 1. Effects of cropping system on OC content.

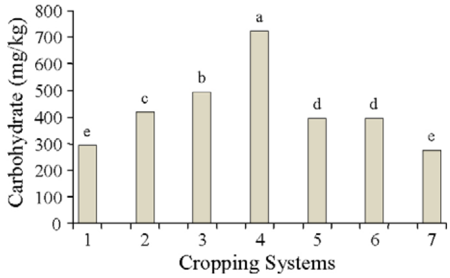

Fig. 2. Effects of cropping system on the amount of hot-water-soluble carbohydrate.

land use changes (Guggenberger et al., 1995). Spaccini et al. (2000) also reported that carbohydrate and humic substances are, respectively, considered as models for the labile and stable fractions of soil OC pool.

3.2. Concentration of carbohydrate pools

Carbohydrate concentration in soil followed almost similar trends of the soil organic carbon content. Significant differences ($P < 0.01$) were obtained in the amount of carbohydrate under different cropping systems. The general trend of the hot-water-soluble carbohydrate concentrations shown in Fig. 2 indicates a general increase in this fraction of carbohydrate from T1 to T4 cropping systems (from almost 300 to 750 mg/kg). The high amounts of carbohydrate in T3 and T4 cropping systems seems to be the result of higher amount of adding manure, and also greater crop yield and hence a higher return of crop residues in these treatments (Debosz et al., 2002; Xiao et al., 2006). More obviously, the lowest quantity of carbohydrate was obtained in T1 and T7 cropping systems, which had no fertilizer added. A period of fallow in a cropping sequence may considerably reduce organic matter content, and consequently, the carbohydrate content (Cheshire, 1979). Comparing the results of T5 and T6 with T7 consistently confirmed the degradative effects of frequent fallow on soil quality, evidenced by increased organic matter loss, depreciated organic matter quality, reduced microbial activity and enhanced susceptibility to erosion (Campbell et al., 1991). The amount of hot-water-soluble carbohydrate in soil was decreased with depth (Table 2).

The values of acid-soluble carbohydrates (Fig. 3) were lower than those of the hot-water-soluble carbohydrates. As with the hot-water-soluble carbohydrate fraction, the acid-soluble fraction was significantly increased ($P < 0.01$) from T1 to T4 cropping system and the lowest amount of carbohydrate was obtained in T1 cropping system. The lower soil depth (5–15 cm) had similar values of acid-soluble carbohydrates comparing to the upper soil depth (Table 2).

The general trend in values of cold-water-soluble carbohydrate among the cropping systems was similar to that obtained from hot-water- and acid-soluble carbohydrate fractions (Fig. 4), the lowest values were obtained for the cold water-soluble carbohydrate concentration (100–300 mg/kg). The amount of cold water-soluble carbohydrate significantly ($P < 0.01$) increased with depth (Table 2).

3.3. Effects of cropping systems on aggregate stability

Although, due to the initially low OM, structureless soil and long time of tillage practices in the area (Hajabbasi and Hemmat, 2000), the mean weight diameters were generally low (not higher than 0.8 mm), cropping systems had significantly different effects on changing the size of water-stable aggregates (Fig. 5). In this respect no differences were observed between the two depths (Table 2). Mean weight diameters were generally increased from T1 (~0.4 mm) to T4 (0.8 mm) cropping systems, indicating that aggregate stability follows the pattern of increasing organic matter content. This is almost opposite to what Tete-Mensah et al. (1999) observed. They proposed that the aggregate stability did not show any consistent pattern with organic matter content of soil. Other reports also showed that changes in aggregate stability following land use changes had little effects on changes in total SOM content which leads to the conclusion that either environment (climate) has a more significant role or only a small fraction of SOM is involved in this task (Haynes and Swift, 1990; Haynes et al., 1991). This is likely that such changes in aggregation are related to labile

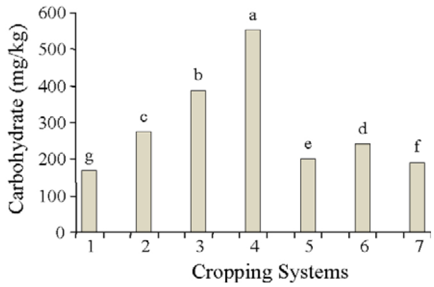

Fig. 3. Effects of cropping system on the amount of acid-soluble carbohydrate.

Table 2
Soil organic carbon, carbohydrate (measured by different methods), and mean weight diameter for two depths (averaged of all treatments)

Parameter	Unit	0–5 cm	5–15 cm
Soil organic carbon	%	2.14a[a]	2.07b
Carbohydrate (hot water)	mg/kg	449a	407b
Carbohydrate (cold water)	mg/kg	158b	162a
Carbohydrate (acid-soluble)	mg/kg	295a	291a
Mean weight diameter	mm	0.54a	0.56a

[a] Means with different letters of each property is significantly different ($P < 0.01$).

Table 3
Relationship between organic matter pools and aggregate stability

Regression equations	Correlation of coefficient
MWD = 0.1109OC + 0.34	0.62**
MWD = 0.0009HW + 0.2[a]	0.74**
MWD = 0.001DA + 0.28	0.73**
MWD = 0.0017CW + 0.29	0.64**

[a] OC and HW, DA and CW, respectively, stands for organic carbon, and hot water, dilute acid and cold water carbohydrate.
** Significant at $P < 0.01$.

Table 4
Effects of cropping systems on soil organic carbon, carbohydrate (hot water, acid-soluble and cold water) and MWD of water stable aggregates

Parameter	Unit	T1[a]	T2	T3	T4	T5	T6	T7
Soil organic carbon	%	0.99e[*]	2.48c	2.85b	3.85a	1.56d	1.54d	1.53d
Carbohydrate (hot water)	mg/kg	293.5e	418.29c	496.49b	723.32a	394.33d	394.79d	289.53e
Carbohydrate (acid-soluble)	mg/kg	169.62f	273.71c	388.42b	552.6a	200.44e	241.56d	171.46f
Carbohydrate (cold water)	mg/kg	109.8e	179.4c	225.6b	286.1a	138.8d	140.2d	105.2e
MWD	mm	0.38f	0.46e	0.62c	0.78a	0.56d	0.69b	0.39f

[a] Treatments are plots annually receiving 0 (T1), 25 (T2), 50 (T3) and 100 (T4) Mg/ha of manure, and plots receiving chemical fertilizer with fallow (T5), and rotations of barely, wheat, corn (T6) and barely, rice, fallow (T7) for the last 3 years (details in Table 1).
[*] Means with different letters in each row are significantly different ($P < 0.01$).

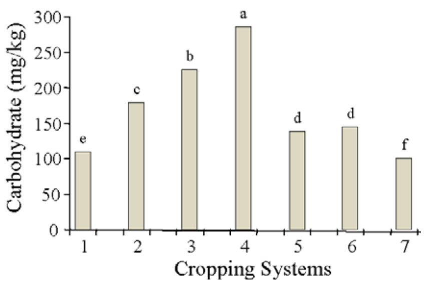

Fig. 4. Effects of cropping systems on the amount of cold-water-soluble carbohydrate.

organic bonding compounds (Alguacil et al., 2005). These bonding compounds contain a combination of transient and temporary organic binding agent (Haynes, 2000). For the T5, T6 and T7 treatments, although similar in OC content, variable amounts of MWD were obtained, which might be due to the cropping system effects. For alfalfa, clover and canola, Martens (2000) suggested that transient aggregate stability is initiated by microbial decomposition of carbohydrates and amino acids of the residues and then in a rotation, strengthened by interaction of phenolic acids such as vanillin or vanillic acid released by microbial decomposition of corn and oat residues. One theory implies that soil polysaccharides from plant and microbial sources play a key role in the stabilization of soil microaggregates (Martin, 1971; Cheshire, 1979). In theory, the binding activity is related to the length and linear structural of polysaccharides that allow them to bridge the space between soil particles (Martin, 1971). Extracellular polysaccharides from bacteria or fungi and roots mucilages are typically labile SOM fractions which are important as binding agents of soil aggregates (Cheshire, 1979; Oades, 1984). Isolated extracellular carbohydrate is shown to be efficient in both formation and stabilization of soil aggregates (Robert and Chenu, 1992).

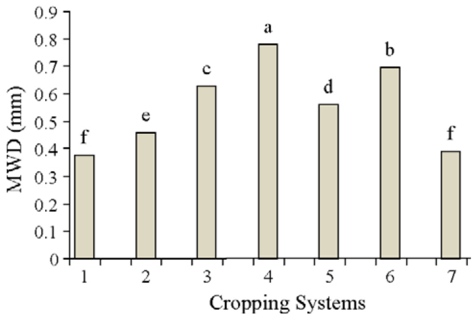

Fig. 5. Effects of cropping systems on MWD of water-stable aggregates.

3.4. Correlation of organic carbon and carbohydrate pools with aggregate stability

Mean weight diameter values were correlated with total OC, acid-soluble, hot-water-soluble and cold-water-soluble carbohydrates to assess the role of OC and the carbohydrate fractions to aggregate stability. The results are presented in Table 3, showing that both OC and carbohydrate fractions, typically hot-water-soluble fraction, are correlated positively and significantly ($P < 0.01$) with MWD. The high correlation coefficient values, mean that both OC and carbohydrate fractions were contributing to aggregate stabilization of soil particles. Carbohydrates are very important bonding agents for soil aggregates (Haynes and Beare, 1996). Moreover, many investigators have found that the amount of carbohydrate in soils is positively correlated with aggregate stability (Tisdall and Oades, 1982; Angers and Mehuys, 1989; Haynes and Francis, 1993). The carbohydrate content of hot water extracts is used as an index of soil quality, particularly in relation to soil aggregation (Haynes and Beare, 1996). Indeed, a number of workers have observed that the hot-water-extractable carbohydrate fraction is more closely related to aggregate stability than total carbohydrates or total organic C of soils (Haynes and Beare, 1997; Haynes and Francis, 1993). Angers et al. (1993) observed that aggregate stability was more closely correlated with hot-water-extractable than dilute-acid-hydrolysable carbohydrates (Table 4).

4. Conclusions

Soil aggregate stability was possibly related to soil organic carbon and carbohydrate contents. Animal manure addition was more effective at improving soil aggregation than cropping systems, even with continuous alfalfa. The soil hot-water-extractable carbohydrates were greater than other carbohydrate fractions. This fraction also showed a better correlation with soil aggregate stability, therefore it might be used as an index of soil aggregate stability and thus soil quality in the region.

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