Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2007 5(3), 431-434
ISSN: 1695-971-X

Short communication. The effect of freeze-thaw cycles on soil aggregate stability in different salinity and sodicity conditions

U. Sahin* and O. Anapali

Department of Agricultural Structures and Irrigation. Faculty of Agriculture. Ataturk University. 25240 Erzurum. Turkey

Abstract

Freezing and thawing affect soil aggregate stability. Understanding the effects of freezing and thawing processes on aggregate stability is necessary for the development of strategies for managing saline-sodic soils. This study was performed to determine the effects of freezing and thawing cycles (two, four, and six) on wet aggregate stability in six soils of different salinity and sodicity (54 dS m^{-1}, 11.7%; 49 dS m^{-1}, 11.8%; 53 dS m^{-1}, 31.7%; 85 dS m^{-1}, 39.7%; 59 dS m^{-1}, 13.9%; 68 dS m^{-1}, 36.8%, respectively) and three different aggregate sizes (< 1, 1-2, and 2-4 mm). The experiments were conducted under laboratory conditions using disturbed and non-cropped soil samples. In soils with a high percentage of exchangeable sodium and high electrical conductivity, the effect of freeze-thaw cycles on the wet aggregate stability was not significant. However, when the electrical conductivity was high and the percentage exchangeable sodium relatively low, wet aggregate stability was significantly reduced by the freeze-thaw cycles. Moreover, for aggregate sizes of 1-2 and 2-4 mm, a significant reduction ($P < 0.01$) was seen in the wet aggregate stability of samples that underwent six freeze-thaw cycles compared to those that underwent two cycles.

Additional key words: saline-sodic soils, soil properties, soil structure.

Resumen

Efecto de ciclos congelación-deshielo en la estabilidad de los agregados del suelo en diversas condiciones de salinidad y sodicidad

Para desarrollar estrategias de manejo de suelos salino-sódicos, es necesario entender los efectos de los procesos de congelación y deshielo sobre la estabilidad de los agregados. Se realizó este estudio para determinar los efectos de ciclos hielo-deshielo (dos, cuatro o seis ciclos) en la estabilidad en agua de agregados en seis suelos con diversos niveles de salinidad y sodicidad (54 dS m^{-1}, 11,7%; 49 dS m^{-1}, 11,8%; 53 dS m^{-1}, 31,7%; 85 dS m^{-1}, 39,7%; 59 dS m^{-1}, 13,9%; 68 dS m^{-1}, 36,8%, respectivamente) y en tres tamaños de agregados (< 1, 1-2, y 2-4 mm). Los experimentos se llevaron a cabo bajo condiciones de laboratorio, usando muestras de suelo disturbadas y no-cosechadas. En suelos con unos altos porcentajes tanto de sodio de cambio como de conductividad eléctrica, el efecto de ciclos hielo-deshielo en la estabilidad en agua de agregados no fue significativo; sin embargo, con una conductividad eléctrica alta y un porcentaje de sodio de cambio relativamente bajo, la estabilidad disminuyó a un nivel significativo. Por otra parte, para los tamaños agregados de 1-2 y 2-4 mm, se observó una disminución significativa ($P < 0,01$) en el porcentaje de agregados estables al agua en las muestras sometidas a seis ciclos de hielo-deshielo respecto de las sometidas a dos ciclos.

Palabras clave adicionales: características del suelo, estructura del suelo, suelos salino-sódicos.

Slow drainage is a major problem in the reclamation of saline-sodic soils. In such soils, the swelling and dispersion of soil aggregates causes the size and number of water-conducting pores (macropores) to decrease, resulting in slow leaching (Abu-Sharar *et al.*, 1987a; Ilyas *et al.*, 1997; Ishiguro and Nakajima, 2000). The salinity-sodicity ratio is the dictating factor determining the effects of salts and sodium on soil structure. Soil dispersion is the primary physical process associated with relatively high sodium concentrations (Hanson *et al.*, 1999; Bauder and Brock, 2001). Soils with a high percentage of exchangeable sodium (PES) but with low

* Corresponding author: ussahin@atauni.edu.tr
ussahin@yahoo.com
Received: 23-11-06; Accepted: 14-05-07.

electrolyte concentrations are unstable and show weak aggregate stability (Abu-Sharar *et al*., 1987b; Oster *et al*., 1999). Flocculation is generally enhanced when the soil solution salinity exceeds a value of approximately 1.5 dS m^{-1} (Hanson *et al*., 1999).

It is well known that freezing and thawing affect soil structure. Consecutive freeze-thaw cycles may negatively affect soil particle aggregation (Lehrsch *et al*., 1991). Many studies have shown that freezing and thawing negatively affect soil structure and aggregation. For example, Oztas and Fayetorbay (2003) reported weak aggregate stability in soils with a high PES after freezing-thawing. Hanay *et al*. (2003) reported that even in the presence of high salinity levels, aggregate stability decreased with increasing numbers of freeze-thaw cycles in soils with a high PES.

Freezing and thawing processes occur especially at the soil surface. Any disturbance of dispersive soils at the surface is likely to result in a rapid decline of their structure and a subsequent reduction in their permeability (Oster *et al.,* 1999). This enhances the possibility of surface soils becoming exposed to wind and water erosion.

Based on Turkish Advanced Soil Map surveys, salinity and sodicity were detected in 1,518,722 ha of the country's land resources. These survey data indicate that saline soils cover a large part of Turkey's barren lands (74%), which together occupy an area almost equal to 2% of the total surface area, 5.48% of the total cultivable land area, and 17% of the 8.5 million ha of economically irrigable land area (Kendirli *et al.,* 2005).

This study was conducted to evaluate the effects of freezing and thawing processes on the stability of different sized aggregates in soils of the Igdir Plain with different salinity and sodicity levels.

The Igdir Plain in northeastern Turkey is one of the country's most important agricultural production areas. It covers 68,000 ha of irrigated land and has a mean slope of 0.1%. The mean altitude is 850 m. About 36% of its soils (25,000 ha) suffer from some degree of salinity and/or alkalinity (Ardahanlioglu *et al*., 2003). The mean annual precipitation, temperature, and relative humidity of the area are 253 mm, 11.7ºC, and 71% respectively (Smith, 1993). The soil humidity and temperature regimes are defined as Aridic and Thermic (Soil Survey Staff, 1975).

Six samples from the 0-30 cm top layer of soils with different salinity and sodicity levels (Typic Natrargids) were collected. Their physical and chemical properties were determined using the methods of Klute (1986) and Page *et al*. (1982) (Table 1). The samples were air dried and sieved into three aggregate size groups (< 1, 1-2, and 2-4 mm). Five hundred grams of each aggregate size group were placed into 1 kg plastic pots with holes. The moisture regime of the aggregates prior to freezing was set to field capacity (–0.33 kPa). The samples of different aggregate size groups were then frozen at –5°C for 24 h in a temperature-controlled freezer and

Table 1. Some physical and chemical properties of the soils studied

Properties	Soil type					
	I	II	III	IV	V	VI
Clay (%)	22	24	18	33	24	17
Silt (%)	53	51	50	53	63	49
Sand (%)	25	25	32	14	13	34
Texture[1]	SiL	SiL	SiL	SiCL	SiL	L
pH (1:2.5)	7.72	7.70	8.85	9.15	8.26	8.80
EC[2] (dS m^{-1})	54	49	53	85	59	68
CEC[3] ($cmol_{(+)}$ kg^{-1})	30.7	30.5	26.2	32.5	28.8	26.6
PES[4] (%)	11.7	11.8	31.7	39.7	13.9	36.8
$CaCO_3$ (%)	7.90	8.10	9.20	9.30	7.80	7.75
Organic matter (%)	3.62	3.80	2.74	2.68	3.60	3.20
Wet aggregate stability (%)						
< 1 mm	2.72	7.22	1.31	0.86	3.97	0.95
1-2 mm	6.43	6.38	1.29	0.17	7.33	1.08
2-4 mm	15.24	6.88	1.22	0.73	4.18	0.73

[1] SiL: silty loam. SiCL: silty clay loam. L: loam. [2] Electrical conductivity (in saturated paste). [3] Cation exchange capacity. [4] Percentage of exchangeable sodium.

subsequently thawed at a cool room temperature (+5°C) for another 24 h. This freezing and thawing procedure was repeated for two, four or six cycles. This sequence is considered to represent the freezing and thawing conditions of early spring on the Igdir Plain.

The percentage of water-stable aggregates was then determined using the wet sieving procedure (Kemper and Rosenau, 1986).

The treatments followed a factorial design: three replications including six soil types, three aggregate size groups, and three freezing-thawing cycles. Analysis of variance (ANOVA) was performed to evaluate the effects of the different treatments. Duncan's multiple test procedure was used to compare the average values obtained (SAS Institute, 1989).

Table 2. Wet aggregate stability values for different soils and aggregate sizes after different numbers of freeze-thaw cycles

	Freeze-thaw cycles	Wet aggregate stability (%)
Soil type		
I	2	3.01 ab[1]
	4	3.07 ab
	6	2.70 bc
II	2	2.54 bc
	4	2.21 cd
	6	2.25 cd
III	2	1.28 fg
	4	1.55 ef
	6	0.86 g
IV	2	0.25 h
	4	0.13 h
	6	0.15 h
V	2	3.44 a
	4	3.05 ab
	6	1.94 de
VI	2	0.99 g
	4	0.97 g
	6	0.98 g
Aggregate size (mm)		
< 1	2	1.78 ab[1]
	4	1.96 a
	6	1.75 ab
1-2	2	1.91 a
	4	1.81 ab
	6	1.48 bc
2-4	2	2.06 a
	4	1.73 ab
	6	1.21 c

[1] Mean followed by the same letter are not significant ($P < 0.01$) according to Duncan's multiple range test.

Table 2 shows the comparison of the mean wet aggregate stabilities of the soil samples for different numbers of freeze-thaw cycles. The effect of these cycles on this variable was not significant in soils I, II, IV and VI. Significant reductions ($P < 0.01$) were seen, however, for soils III and V after six freeze-thaw cycles. Soil III contains less organic matter and clay than the other soils (Table 1). An increasing number of freeze-thaw cycles may have a negative effect on the aggregate stability of soils with less organic matter (Lehrsch *et al.*, 1991). Further, low clay contents may enhance the negative effect caused by a high PES in such soil. Soil V had the highest amount of silt; Pikul and Allmaras (1985) report that frequent freezing and thawing of silt loam soils may seriously degrade their structure.

The effect of freezing-thawing cycles was not significant for aggregate sizes of less than 1 mm (Table 2). For the 1-2 mm and 2-4 mm aggregate size groups, a significant reduction ($P < 0.01$) in wet aggregate stability occurred after six freeze-thaw cycles with respect to two freeze-thaw cycles. Benoit (1973) found that the greatest reduction in the percentage of water-stable aggregates following freezing and thawing occurred within the largest aggregate size groups.

At the end of the six freeze-thaw cycles, no significant alterations were seen in the wet aggregate stability of any of the aggregate sizes of soils III, IV and VI (Fig. 1). Soils III, IV and VI had higher PES values (Table 1). These soils initially showed low aggregate stability, in agreement with that reported by Abu-Sharar *et al*. (1987b) and Oster *et al*. (1999). Weakly aggregated soils with a high PES may therefore be less affected by freezing-thawing.

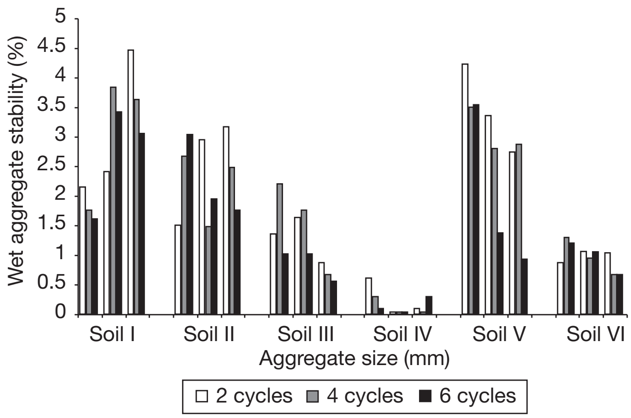

Figure 1. Wet aggregate stability of soils with different aggregate sizes (from left to right, < 1, 1-2, 2-4 mm) after different number of freeze-thaw cycles ($LSD_{0.01} = 0.92$).

In conclusion, this study reports the following findings: i) at the end of six freeze-thaw cycles, the wet aggregate stability of soils III and V was significantly reduced; ii) in soils with a high PES and electrical conductivity, the effect of freeze-thaw cycles on the wet aggregate stability is insignificant; however when the electrical conductivity is high and PES relatively low, the wet aggregate stability decreases significantly with increasing numbers of freeze-thaw cycles.

References

ABU-SHARAR T.M., BINGHAM F.T., RHOADES J.D., 1987a. Reduction in hydraulic conductivity in relation to clay dispersion and disaggregation. Soil Sci Soc Am J 51, 342-346.

ABU-SHARAR T.M., BINGHAM F.T., RHOADES J.D., 1987b. Stability of soil aggregates as affected by electrolyte concentration and composition. Soil Sci Soc Am J 51, 309-314.

ARDAHANLIOGLU O., OZTAS T., EVREN S., YILMAZ H., YILDIRIM Z.N., 2003. Spatial variability of exchangeable sodium, electrical conductivity, soil pH and boron content in salt- and sodium-affected areas of the Igdir plain (Turkey). J Arid Environ 54, 495-503.

BAUDER J.W., BROCK T.A., 2001. Irrigation water quality, soil amendment, and crop effects on sodium leaching. Arid Land Res Manage 15, 101-113.

BENOIT G.R., 1973. Effect of freeze-thaw cycles on aggregate stability and hydraulic conductivity of three soil aggregate sizes. Soil Sci Soc Am Proc 37, 3-5.

HANAY A., SAHIN U., ANAPALI O., 2003. Decrease in hydraulic conductivity of clay soils with salinity-sodicity problems due to freezing and thawing effect. Acta Agr Scan Sec B-Soil Plant Sci 53, 208-210.

HANSON B., GRATTAN S.R., FULTON A., 1999. Agricultural salinity and drainage. University of California, Irrigation Program, Davis, USA.

ILYAS M., QURESHI R.H., QADIR M.A., 1997. Chemical changes in a saline-sodic soil after gypsum application and cropping. Soil Tech 10, 247-260.

ISHIGURO M., NAKAJIMA T., 2000. Hydraulic conductivity of an allophanic andisol leached with dilute acid solutions. Soil Sci Soc Am J 64, 813-818.

KEMPER W.D., ROSENAU R.C., 1986. Aggregate stability and size distribution. In: Methods of soil analysis, physical and mineralogical properties. Part I, 2nd ed (Klute A., ed). ASA-SSSA, Madison, WI. pp. 425-442.

KENDIRLI B., CAKMAK B., UCAR Y., 2005. Salinity in the southeastern Anatolia project (GAP), Turkey: issues and options. Irrig and Drain 54, 115-122.

KLUTE A., 1986. Methods of soil analysis. Physical and mineralogical properties. Part I, 2nd ed. ASA-SSSA, Madison, WI. 1173 pp.

LEHRSCH G.A., SOJKA R.E., CARTER D.L., JOLLEY P.M., 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. Soil Sci Soc Am J 55, 1401-1406.

OSTER J.D., SHAINBERG I., ABROL IP., 1999. Reclamation of salt-affected soils. In: Agricultural drainage (Skaggs R.W., Schilfgaarde J.V., eds). ASA-CSSA-SSSA, Madison, WI. pp. 659-691.

OZTAS T., FAYETORBAY F., 2003. Effect of freezing and thawing process on soil aggregate stability. Catena 52, 1-8.

PAGE A.L., MILLER R.H., KEENEY D.R., 1982. Methods of soil analysis. Chemical and microbiological properties, Part II, 2nd ed. ASA-SSSA, Madison, WI. 1143 pp.

PIKUL J.L., ALLMARAS R.R., 1985. Hydraulic potential in unfrozen soil in response to diurnal freezing and thawing of the soil surface. T ASAE 28, 164-168.

SAS INSTITUTE, 1989. SAS/STAT user's guide (Ver. 6, 4th ed). SAS Institute, Cary, NC.

SMITH M., 1993. CLIMWAT for CROPWAT, a climatic database for irrigation planning and management. FAO Irrigation and Drainage Paper No: 49, Rome, Italy.

SOIL SURVEY STAFF, 1975. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. United States Department of Agriculture Handbook No. 436, Washington, D.C.