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STUDIES ON FREEZING AND THAWING SOILS IN IOWA[†]

JERRY K. RADKE[‡] AND EDWIN C. BERRY

ABSTRACT

Frozen soils have a major influence on the cropping systems and farming practices in northern states. However, relatively little research has been done on the physical, chemical, and biological processes that occur in the field during the non-growing season. Experiments on frozen soils were started recently in Iowa to 1) study the effects of residue cover on soil freezing and thawing, 2) measure the movement of water and solutes and changes in soil structure due to freezing and thawing of repacked soil columns in the field, 3) test the SHAW (Simultaneous Heat And Water) model for its capability to predict freeze/thaw cycles, and 4) determine the effect of freeze/thaw and wetting/drying cycles on soil cracking. Residue cover changed freeze/thaw rates and frost depth. Water moved to the freezing front which resulted in a net upward movement after thawing. Solute movement was more complex because of its movement with water, its exclusion from water during freezing, and its redistribution during and after thawing. The SHAW model provided reasonable agreement with measured frost depth during the winter of 1993-1994. These studies are continuing and will aid in the development of management practices to protect our soil resources while sustaining a productive agriculture.

INTRODUCTION

The overwinter effects on agricultural crops and fields caused by freezing and thawing of soils has been observed in Iowa and other northern states since the beginning of modern agriculture (1, 2, 3). Frost heaving can kill plants (4, 5) as well as damage roads and structures (6). The ability of crops to overwinter in this area depends on the severity of the winter, the amount of snow cover, the number of freeze-thaw cycles, and the amount of water in the soil profile. Soil structure is determined to some degree by the process of freezing and thawing (7). Freezing and thawing effects movement of water and solutes in the soil (8), aggregate formation (7), and water and wind erosion (9). Sublimation or freeze-drying effects on the frozen soil surface can leave the surface soil in an erodible condition. Winter dust storms are often a result of this process combined with high winds.

A classic soil physics experiment demonstrates the ability of the freezing process in soils to move water to the frost layer and form ice layers or lenses (10, 11). A soil column is supplied with water from a reservoir below the column. The soil column and water reservoir is insulated exposing only the top of the soil (Fig. 1). A weight may be placed on top of the soil to provide downward pressure. The insulated soil column is placed in a freezer. Water moves upward to the ice layer forming at the freezing front until the soil immediately below becomes too dry. At this time, the freezing front moves further down into the soil profile and a new ice layer starts to form. With a specific water content and freezing rate, several ice layers can form with relatively dry soil layers between them. As water freezes into ice crystals, pressure on the surrounding soil aggregates forces them apart and may compress or rupture them. Although, it is more common for ice crystals or ice lenses to be observed in the field (12), ice layering can occur as described above.

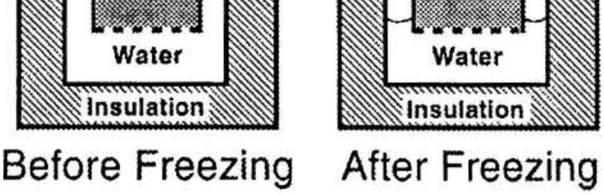

Fig. 1. A classic soil physics experiment showing ice lens formation in a freezing soil.

Adapted from Taber (10)

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As ice crystals or lenses form, salt is excluded from the ice and a concentration of salt in solution occurs at the edges (8). This greater concentration of solute lowers the freezing temperature further (13). Thus, at any time in frozen soil, there may be ice crystals and unfrozen solution throughout the frozen soil matrix (14). This leads to many complex possibilities in regards to physical, chemical, and biological states and processes.

The objective of this paper is to discuss research initiated at the National Soil Tilth Laboratory in Ames, Iowa. Firstly, near Adel, Iowa, we are gathering overwinter soils data under management systems with different amounts of residue cover. Secondly, we are studying buried soil columns near Ankeny, Iowa to determine the movement of water and solutes and changes in physical and biological properties. Thirdly, we are using the SHAW (Simultaneous Heat And Water) model (15) to predict changes in soil properties due to soil freezing and thawing under various climatic conditions. And finally, we are comparing cracking patterns between soil blocks frozen before drying and soil blocks dried without prior freezing.

EXPERIMENTAL PROCEDURE

Adel Residue Cover Experiment

A field study was initiated in 1991 to determine the effects different amounts of grass-clipping mulch have on soil temperature and depth of overwinter freezing. Plots were established on an eroded knoll of Ladoga silt loam (fine, montmorillonitic, mesic Mollic Hapludalfs) located on the Gustafson Research Farm near Adel, Iowa. The experiment had six treatments consisting of 0, 750, 1500, 2250, 3000, and 3750 kg ha^{-1} of grass clippings. Each 750 kg ha^{-1} of grass clippings was equivalent to a layer about 5 cm deep. Plots were 10 m by 10 m wide with a 3 m alley between them. Four CRREL (Cold Regions Research and Engineering Laboratory)-type frost tubes (16) were placed in each of the six plots. Three plots (0, 2250, and 3750 kg ha^{-1}) were instrumented with 1-m soil temperature probes read hourly with Campbell 21X data loggers.§ Temperature probes had copper-constantan thermocouples positioned at 1, 5, 10, 15, 25, 50, and 100 cm beneath the soil surface.

Ankeny, Iowa Soil Column Experiment

Twenty-four 12.7 cm diameter, 117 cm long soil columns were packed to a bulk density of 1.4 gm cm^{-3} with Webster clay loam soil in October 1993. Soil was sieved through a 1.25 cm sieve to remove large clods and grass roots. Soil was packed in each column by putting 935 g (at 5% water content) of soil into successive 5-cm layers until the column was full. Water was added to each of the 5-cm layers during packing to give a gravimetric water content of 20% in 12 of the columns. The other 12 columns were fitted on the bottom with a nylon screen and an end cap tapped with a 1.25 cm diameter hose barb; they were saturated from the bottom and allowed to drain to field water capacity (FC). Potassium bromide (KBr) was added to the two layers from 5 cm to 15 cm below the soil surface to simulate the addition of N fertilizer at a rate of 150 kg ha^{-1}. Five adult *Lumbricus terrestris* earthworms were added to half of the 20% and FC columns. The top and bottom of each soil column was covered with plastic bags to minimize water loss until the columns were installed in the field.

Twenty-four 15.2 cm diameter cylinders were installed into holes dug with a tractor-mounted post-hole digger on November 12, 1993; these cylinders served as casings for the soil columns. Casings were placed in a Webster silty clay loam (fine-loamy, mixed mesic Typic Haplaqualls) soil and arranged in two groups with individual casings spaced 1 m apart. A weather station was situated between the two groups. Soil columns were inserted into the casings and the top space between the cylinders packed with fiberglass insulation and sealed with duct tape. The bottom of the soil columns were in contact with the field soil so water could move in and out of the columns. Soil columns were sampled in groups of four at various times during the winter. The six sampling dates were January 10, January 11, February 9 and 10, February 22 and 23, March 14, and March 22 and 23 (Table 1). Four columns sampled on January 11 were used for infiltration tests (data are not presented).

Unfrozen soil was removed from the bottom of the columns in 5-cm layers with a special jig and a custom-made 12.7 cm diameter soil auger. The frozen portion of the soil was cut into 5-cm layers using a chop saw fitted with a coarse-cut, carbide-tipped blade after either cutting away the plastic cylinder from the soil or pressing the frozen soil out of the cylinder. The 5-cm layer consisting of part frozen and part unfrozen soil was separated into two sections and each processed separately. Each layer was analyzed for gravimetric water content, bulk density, and electrical conductivity.

Six CRREL-type frost tubes (16) were installed between the soil columns. Soil temperatures at depths of 2, 5, 10, 15, 25, 50, 75, and 100 cm, air temperature, solar radiation, and rainfall were recorded at the weather station. Snow depth, density and water content were measured after each precipitation event or two or three times weekly. Weather station data

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§ The USDA neither guarantees nor warrants the standard of the product, and the use of the name does not imply approval of the product to the exclusion of others that may be suitable.

Table 1.

Summary table showing the setup, sampling dates, frost depths, ice crystal depths for repacked, soil-column experiment near Ankeny, IA during the winter of 1993-1994.

Col.	Wetting Method	Earth worms Present	Sampling Date	Depth to Frost Layer	Depth to Frost Crystals
#			Mo/Day/Yr	--------cm--------	
1	20%	No	01/10/94	23.5	0.0
2	20%	Yes	01/10/94	26.5	0.0
3	Field Capacity	No	01/10/94	24.2	0.0
4	Field Capacity	Yes	01/10/94	22.7	0.0
5	20%	No	01/11/94	N/S	N/S[†]
6	20%	Yes	01/11/94	N/S	N/S
7	Field Capacity	No	01/11/94	N/S	N/S
8	Field Capacity	Yes	01/11/94	N/S	N/S
9	20%	No	02/09/94	63.2	0.0
10	20%	Yes	02/10/94	60.1	0.0
11	Field Capacity	No	02/10/94	65.6	0.0
12	Field Capacity	Yes	02/09/94	63.1	0.0
13	20%	No	02/22/94	4.0	54.0
14	20%	Yes	02/23/94	6.0	59.0
15	Field Capacity	No	02/23/94	5.5	48.5
16	Field Capacity	Yes	02/22/94	7.7	60.2
17	20%	No	03/14/94	0.0	0.0
18	20%	Yes	03/14/94	0.0	50.0
19	Field Capacity	No	03/14/94	0.0	70.0
20	Field Capacity	Yes	03/14/94	0.0	0.0
21	20%	No	03/22/94	0.0	0.0
22	20%	Yes	03/22/94	0.0	50.0
23	Field Capacity	No	03/23/94	0.0	50.0
24	Field Capacity	Yes	03/23/94	0.0	0.0

[†] N/S : Not Sampled

was used in the SHAW model (15, 17) to predict frost depth and the number of freeze-thaw cycles.

Soil Cracking Experiment

Four metal pans, 30.5 cm by 30.5 cm by 15.0 cm depth were filled with soils – two with a Webster silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls) top soil from a natural pothole and two with subsoil from a Nicollet clay loam (fine-loamy, mixed, mesic Aquic Hapludolls). After the soil blocks were wet to near field capacity, one block of each soil type was frozen for 17 hours in a walk-in freezer while the other two were covered to prevent evaporation. After freezing, the two frozen blocks and the two unfrozen blocks were allowed to dry at room temperature. Crack formation was observed and photographed for each pan for several days. The blocks then were rewet and allowed to dry a second time.

RESULTS

Adel Residue Cover Experiment

Frost depth measured with frost tubes was noticeably affected by the 15-cm (2250 kg ha^{-1}) and 25-cm (3750 kg ha^{-1}) depths of grass residue cover (Fig. 2). The rate of thawing from the surface also was decreased and is shown most dramatically by the frost tube measurements taken on December 11, 1991. The layer of insulation provided by the residue cover effectively changed the amplitude of the diurnal soil temperature fluctuations with the smallest amplitude under the greatest amount of cover (data not shown). Increased grass cover reduced the rate of freezing and the maximal frost depth and also decreased the rate of thawing. Residue cover and snow cover are both effective ways to modify the overwinter freeze/thaw cycles in the soil. The soil temperature profile obtained with the thermocouple probe agreed well with less frequent frost tube measurements.

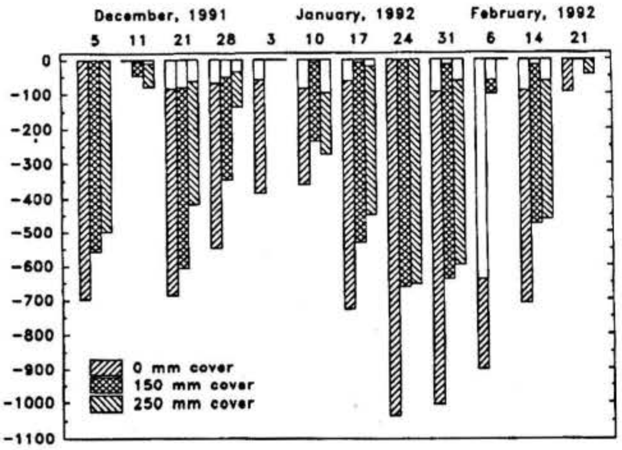


Fig. 2. Frost depths measured with CRREL frost tubes under 0, 15, and 25 cm of grass residue cover for 12 dates during the winter of 1991-1992 near Adel, Iowa. Open portions of the bars represent thawed (unfrozen) soil near the surface.

Ankeny Soil Column Experiment

Water contents, bulk densities, and electrical conductivities with depth for soil column 4 (sampled January 10, 1994) are shown in Fig. 3 as an example. Note the changes in the soil properties at or above the ice boundary. There was considerable variation in the shape of these curves from column to column even within sampling dates. Therefore, means for soil layers across column replicates or treatments were not calculated.

There was movement of water in and out of the bottoms of the soil columns between the dates of installation and sampling because the columns were in contact with the field soil. The columns wet to field capacity maintained greater water contents in the top portion than those packed at 20% gravimetric water content; however, the water contents in the bottom portion of the columns were similar (Table 2) because of water movement past the bottom of the column. The mean frost depth in the soil columns sampled on January 10, 1994 was 24.2 cm (Table 1). Frost depths for the columns sampled on February 9 and 10 averaged 63.0 cm and those sampled on February 22 and 23 averaged 5.8 cm. Water contents generally were greater in the frozen soil than in the unfrozen soil below it because of water movement to the frozen zone (Fig. 3).

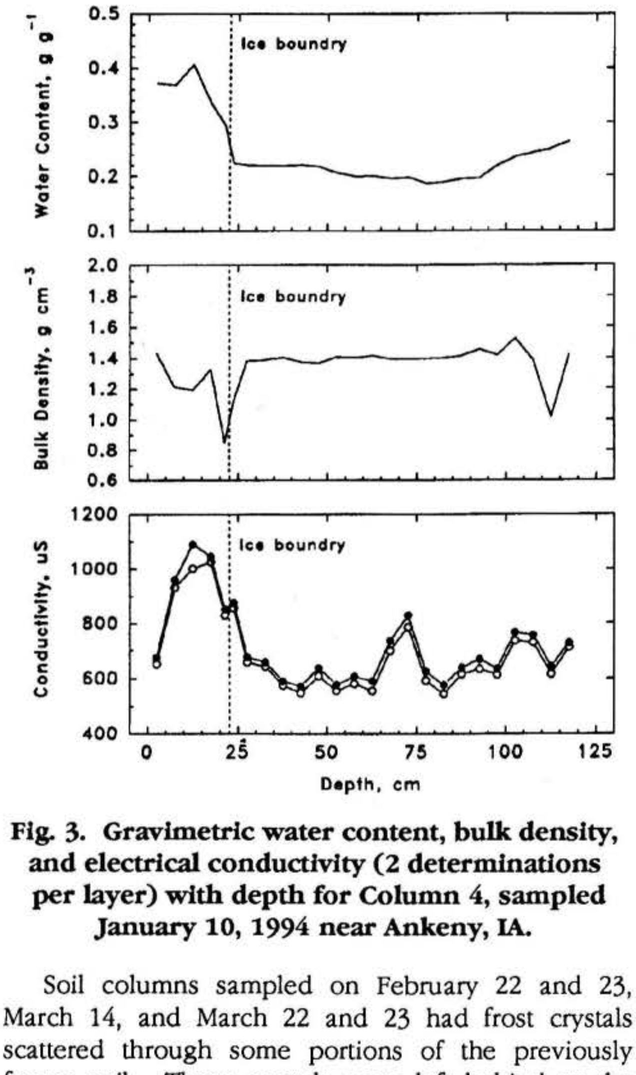


Fig. 3. Gravimetric water content, bulk density, and electrical conductivity (2 determinations per layer) with depth for Column 4, sampled January 10, 1994 near Ankeny, IA.

Soil columns sampled on February 22 and 23, March 14, and March 22 and 23 had frost crystals scattered through some portions of the previously frozen soil. These crystals were left behind as the frozen zone thawed upwards. Large ice lenses and crystals did not have time to completely thaw before the solid frost layer retreated. Some re-equilibration of water content occurred upon thawing; however, a net upward concentration of water in the profile was still observed (data not presented).

Localized change in soil bulk density occurs as ice lenses and crystals form. Soil compaction occurs as ice lenses force soil particles and aggregates closer together. Larger voids may remain in the soil when these ice lenses thaw. Bulk densities measured in the frozen zone tend to be variable because of this segregation (Table 3). Bulk densities at the freezing front can be much greater or lesser than normal. This is partially due to the difficulty of accurately measuring the soil volumes just above and just below the frozen interface.

Some solute movement is evident from the electrical conductivity measurements presented in Table 4. Greater conductivities occur in the second, third, and fourth layers (5 to 15 cm depths) that had KBr added. There is an indication that some net downward movement of the KBr occurred. Conductivities were lesser for the later sampling dates suggesting a possible loss of the KBr from the soil column, although we are not sure how this may have happened. It is possible that some loss occurred through the top of the columns due to periods of flooding which covered some columns and the surrounding soil at various times during the winter and spring. Some KBr may have leached through the columns.

Our initial observations are 1) water moves in conjunction with a freezing front in soil, 2) solute moves with the water to the freezing front but then some exclusion from the ice lens forms a brine below the frozen interface, and 3) that changes in bulk density and soil structure occur because of forces developed by formation of ice lenses and crystals.

The weather station data were used in the SHAW model to simulate the freezing and thawing processes observed in the soil columns. Data from the frost tubes, the soil columns, the SHAW model, and the temperature probe are compared in Fig. 4. The SHAW model predicted a shallower maximal frost depth than measured with the frost tubes or the temperature probe. Some of this difference is accountable to a slight freezing point depression in the soil which is not reflected by measurements from the frost tubes or the temperature probe. Soil temperatures that differed only a few tenths of a degree extended over several centimeters of depth. Frost depths in the soil columns were between the frost-depth curves for the frost tubes and the model prediction. The SHAW model appears to give adequate predictions of frost depth in this initial comparison.

Soil Cracking Experiment

Wet soils in metal boxes showed different cracking patterns when frozen before drying compared to those dried without prior freezing. The cracking configuration on the frozen Nicollet subsoil was similar to a river tributary pattern; whereas, the unfrozen soil showed a blocky or "turtle-back" pattern after drying (Fig. 5). Crack width increased with continued drying and additional smaller cracks

Table 2. Water contents in each of the 5-cm layers for each soil-column sampled (Ankeny, IA, 1993-1994).†

	January 10, 1994				February 9-10, 1994				February 22-23, 1994			
	----20%----		--Field Capacity--		----20%----		--Field Capacity--		----20%----		--Field Capacity--	
Column **Layer**	**1**	**2**	**3**	**4**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	37.8	37.4	64.1	37.2	56.6	54.9	48.8	49.2	38.8	42.4	40.9	36.7
2	25.7	32.7	39.3	36.8	43.8	31.9	33.1	36.7	27.3	31.2	30.8	30.8
3	24.9	27.3	32.1	40.6	31.7	26.1	37.5	29.7	26.6	29.6	28.8	28.9
4	25.6	25.3	38.7	33.4	23.9	26.4	32.6	32.3	26.9	29.2	26.9	30.0
5	23.1	22.7	31.2	29.5	23.2	22.8	28.4	29.1	25.9	29.3	27.4	27.3
	20.5			22.4								
6	20.3	22.7	28.2	22.0	24.4	23.5	25.0	26.7	26.3	28.1	26.7	27.5
		22.2	23.8									
7	21.6	21.4	22.2	21.9	22.3	22.3	22.7	29.0	25.8	28.2	26.3	27.4
8	21.4	22.0	21.3	21.9	22.1	22.1	23.1	24.5	26.4	27.5	26.7	26.9
9	20.1	21.3	21.7	22.1	23.1	20.7	21.4	26.0	25.8	25.0	26.5	20.5
10	20.2	21.6	20.9	21.7	22.3	21.6	20.5	28.0	25.6	24.9	26.2	34.1
11	21.3	20.3	20.5	20.6	22.1	20.6	21.6	27.0	25.6	25.2	25.9	27.0
12	20.7	21.3	19.9	19.9	20.7	22.3	21.3	25.0	24.7	24.3	26.6	27.1
					17.8	----	21.0	23.3				
13	19.3	21.3	21.7	20.0	20.6	20.8	21.6	21.8	24.2	23.7	26.0	26.4
14	20.7	20.5	20.0	19.5	20.7	21.8	23.0	23.0	23.9	23.0	26.3	26.1
15	20.1	20.8	21.5	19.7	21.2	22.5	23.4	23.7	23.5	23.1	25.9	24.3
16	20.1	20.7	19.2	18.7	21.7	22.9	23.9	24.1	22.8	22.8	26.3	24.1
17	20.5	21.5	19.7	19.0	22.5	23.6	25.0	24.6	23.1	22.8	26.0	24.7
18	21.2	21.4	20.4	19.5	22.1	25.0	26.5	24.9	----	22.6	26.0	25.1
19	22.1	21.7	21.1	19.6	22.6	25.6	26.8	25.2	24.6	23.3	26.0	25.6

†Data below the underlined values are for unfrozen soil and those above are for frozen soil. The value just above the underline represents the frozen part and the value just below represents the unfrozen part of the 5-cm layer.

Table 3. Soil bulk density in each of the 5-cm layers for each soil-column sampled (Ankeny, IA, 1993-1994)†

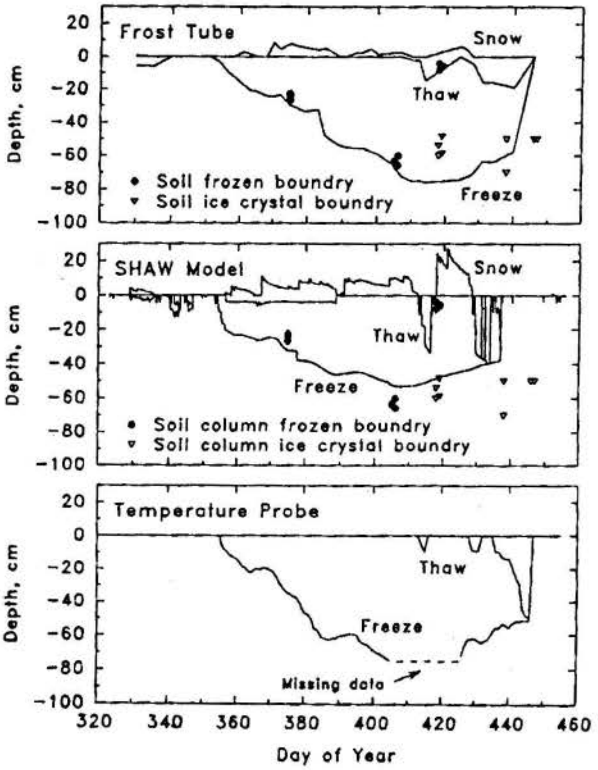
	January 10, 1994				February 9-10, 1994				February 22-23, 1994			
	----20%----		--Field Capacity--		----20%----		--Field Capacity--		----20%----		--Field Capacity--	
Column **Layer**	**1**	**2**	**3**	**4**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	1.54	0.85	1.34	1.43	0.89	0.90	1.01	0.98	1.20	1.01	1.48	1.13
2	0.98	1.30	1.49	1.21	1.08	1.22	1.24	1.22	1.03	1.24	1.15	1.24
3	1.79	1.26	1.31	1.19	1.27	1.33	1.23	1.37	1.46	1.09	1.21	1.31
4	1.18	1.12	1.14	1.33	1.32	1.35	1.14	1.20	1.20	1.06	1.13	1.17
5	1.33	1.46	1.47	0.85	1.21	1.40	1.43	1.31	1.28	0.96	1.31	1.29
	1.54			1.12								
6	1.28	1.47	1.31	1.38	1.36	1.35	1.43	1.41	1.38	1.14	1.38	1.28
		1.10										
7	1.39	1.37	1.44	1.39	1.35	1.12	1.40	1.38	1.31	1.02	1.31	1.46
8	1.29	1.37	1.38	1.41	1.29	1.27	1.40	1.43	1.34	1.32	1.44	1.43
9	1.16	1.34	1.38	1.37	1.33	1.26	1.38	1.41	1.38	1.38	1.31	1.45
10	1.32	1.41	1.39	1.37	1.32	1.37	1.40	1.41	1.42	1.36	1.26	1.38
11	1.32	1.35	1.38	1.41	1.17	1.39	1.30	1.43	1.38	1.34	1.47	1.62
12	1.17	1.40	1.38	1.40	1.31	1.46	1.30	1.59	1.43	1.41	1.36	1.33
					0.94	----	1.36	2.02				
13	1.31	1.32	1.43	1.42	1.31	1.30	1.36	1.38	1.46	1.44	1.34	1.49
14	1.35	1.44	1.44	1.39	1.34	1.39	1.35	1.42	1.47	1.39	1.34	1.32
15	1.30	1.40	1.41	1.39	1.41	1.34	1.39	1.36	1.43	1.43	1.39	1.45
16	1.34	1.32	1.41	1.40	1.39	1.34	1.42	1.48	1.37	1.39	1.36	1.31
17	1.33	1.38	1.41	1.40	1.37	1.33	1.41	1.30	1.34	1.44	1.31	1.39
18	1.31	1.43	1.42	1.41	1.41	1.35	1.36	1.39	----	1.48	1.36	1.37
19	1.34	1.35	1.40	1.46	1.42	1.30	1.35	1.29	1.32	1.30	1.42	1.35

†Data below the underlined values are for unfrozen soil and those above are for frozen soil. The value just above the underline represents the frozen part and the value just below represents the unfrozen part of the 5-cm layer.

Table 4. Soil electrical conductivity in each of the 5-cm layers for each soil-column sampled (Ankeny, IA, 1993-1994)†

	January 10, 1994				February 9-10, 1994				February 22-23, 1994			
	----20%----		--Field Capacity--		----20%----		--Field Capacity--		----20%----		--Field Capacity--	
Column **Layer**	**1**	**2**	**3**	**4**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	740	723	738	664	443	472	554	655	$\underline{511}$	$\underline{520}$	$\underline{523}$	$\underline{593}$
2	878	826	844	947	510	662	656	698	349	639	610	589
3	1070	1033	897	1046	870	863	690	646	593	703	537	600
4	854	1301	935	1035	987	616	632	645	641	814	482	587
5	$\underline{760}$ 631	1026	784	$\underline{842}$ 867	892	637	514	609	695	758	468	494
6	697	$\underline{819}$ 838	$\underline{728}$ 737	667	681	576	456	461	677	752	440	448
7	737	720	625	650	625	553	434	457	625	804	423	413
8	733	859	606	584	585	547	430	447	627	780	394	433
9	741	705	556	560	655	500	440	486	514	640	438	434
10	696	786	565	623	628	556	483	446	482	621	400	431
11	657	747	588	568	618	540	479	454	481	604	398	430
12	667	728	666	594	$\underline{587}$ 571	$\underline{561}$ —	$\underline{450}$ 443	$\underline{445}$ 463	444	528	384	—
13	696	825	548	574	617	553	460	459	444	556	391	402
14	774	764	593	716	609	567	443	472	470	513	381	412
15	822	747	687	807	564	572	444	473	501	476	374	417
16	750	803	580	609	567	559	440	462	494	549	379	408
17	730	760	598	561	587	586	437	458	479	524	374	402
18	708	724	637	627	614	609	430	452	423	564	398	388
19	649	762	569	651	659	655	446	455	581	618	386	407

†Data below the underlined values are for unfrozen soil and those above are for frozen soil. The value just above the underline represents the frozen part and the value just below represents the unfrozen part of the 5-cm layer.



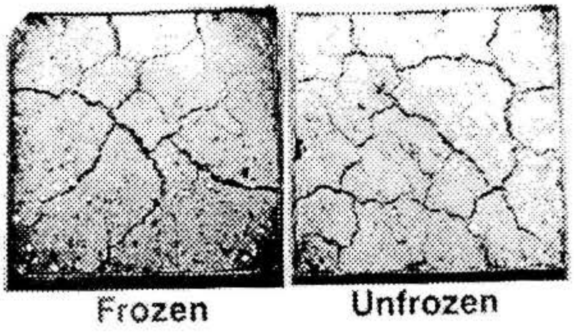


Fig. 5. Soil cracks formed by drying a frozen soil block and an unfrozen soil block.

Fig. 4. Comparison graphs of frost and snow depths for the winter of 1993-1994 near Ankeny, IA. Measured frost depths in repacked soil columns are compared to frost tube measurements adjacent to the soil columns in the top graph. The SHAW model predictions are compared to the soil-column frost depths in the center graph, and the 0 C. temperature isoline is shown in the bottom graph.

appeared as the soil dried. Slowly rewetting the soil block resulted in a reverse action: the finer cracks swelled shut first and the larger cracks became narrower. The larger cracks finally closed with complete rewetting. Drying the soils a second time after complete rewetting resulted in crack patterns similar to the first drying cycle, that is, a river pattern for the soil blocks that had been frozen and a blocky pattern for the unfrozen soil blocks. However, cracks did not form in the same places in the second drying cycle as they did in the first. Obviously, this only occurred when the previous cracks had completely swelled shut with rewetting. Very similar results were obtained with the Webster surface soil blocks. There was some indication that the frozen soil blocks had a mellower structure; however, additional research is needed to confirm this observation.

SUMMARY AND CONCLUSIONS

Data presented are preliminary because most of these experiments are continuing. Overwinter management options are important to the farmer concerned with the survival of winter crops, insects, or diseases. Cover crops, crop residues, and tillage can be managed to manipulate the freeze-thaw processes in the soil. Crop stubble and surface roughness increase snow catch. Snow cover is an even better insulator than residue cover. Good insulation increases the chance for crop survival but could also allow increased pest infestations the following year. Good management requires an understanding of all organisms involved as well as the physical and chemical processes occurring during the freeze-thaw cycles. More study is needed to develop good integrative management practices.

Movement of water and solutes and the effects of freezing forces on soil structure were demonstrated in the Ankeny experiment. Variability of formation of ice lenses in frozen soil columns makes it almost impossible to do layer by layer comparisons from soil column to soil column. There is generally, however, a noticeable demarcation in soil water content, bulk density, and/or electrical conductivity at the frozen interface, at least during the first freeze cycle. Water moves upward to the freezing zone and even though there is some reverse movement during thawing, net movement was upward. Solutes tend to be concentrated into "briny" pools or films during the freezing process but a re-equilibration occurs during thawing. Net movement of solutes depends on many factors, but the potential leaching with downward movement of water caused by spring melt and rains may be of the most concern. Soil structural changes from freezing and thawing obviously occur, but more study is needed on this subject. Freezing forces probably cause both aggregative and disaggregative effects depending on the soil types, water contents, and climatic conditions.

Research on frozen soils is needed so effective, overwinter, management practices can be developed. Coupling these practices with good crop-season conservation and production methods should result in productive agronomic systems.

REFERENCES

1. Brown, P.E. and P.E. Smith. 1912. Bacterial activities in frozen soils. Iowa St. Coll. Agric. Expt. Sta. Res. Bull. no. 4. p. 160-184.
2. DeLuca, T.H., D.R. Keeney, and G.W. McCarty. 1992. Effect of freeze-thaw events on mineralization of soil nitrogen. Biol. Fert. Soils. 14:116-120.
3. McCarty, G.W. and J.M. Bremner. 1993. Factors affecting the availability of organic carbon for denitrification of nitrate in subsoils. Biol. Fert. Soils. 15:132-136.
4. Portz, H.L. 1967. Frost heaving of soil and plants I. Incidence of frost heaving of forage plants and meteorological relationships. Agron. J. 59:341-344.
5. Van Keuren, R.W. 1988. Frost heave of alfalfa as affected by harvest schedule. Agron. J. 80:626-631.
6. Williams, P.J. and M.W. Smith. 1989. *The Frozen Earth: Fundamentals of Geocryology.* 306 p. Cambridge University Press. New York.
7. Bullock, M.S., W.D. Kemper, and S.D. Nelson. 1988. Soil cohesion as affected by freezing, water content, time and tillage. Soil Sci. Soc. Am. J. 52:770-776.
8. Cary, J.W., R.I. Papendick, and G.S. Campbell. 1979. Water and salt movement in unsaturated frozen soil: principles and field observations. Soil Sci. Soc. Am. J. 43:3-8.
9. Siddoway, F.H. and A.P. Barnett. 1976. Water and wind erosion control aspects of multiple cropping. pp. 317-336. In R.I. Papendick, P.A. Sanchez, and G.B. Triplett, eds. Multiple Cropping. Spec. Pub. No. 27. Am. Soc. Agron., Madison, WI. 1976.
10. Taber, S. 1930. The mechanics of frost heaving. J. Geol. 38:303-317.
11. Miller, R.D. 1980. Chapt 11. Freezing phenomena in soils. pp. 254-299. *In* Daniel Hillel, *ed.,* Applications of Soil Physics. Academic Press. New York.
12. Kay, B.D., C.D. Grant, and P.H. Groenevelt. 1985. Significance of ground freezing on soil bulk density under zero tillage. Soil Sci. Soc. Am. J. 49:973-978.
13. Fuchs, M., G.S. Campbell, and R.I. Papendick. 1978. An analysis of sensible and latent heat flow in a partially frozen unsaturated soil. Soil Sci. Soc. Am. J. 42:379-385.

14. Dirksen, C. and R.D. Miller. 1966. Closed-system freezing of unsaturated soil. Soil Sci. Soc. Am. Proc. 30:168-173.
15. Flerchinger, G.N. and K.E. Saxton. 1989. Simultaneous heat and water model of a freezing snow-residue-soil system II. Field verification. Trans. ASAE. 32:573-578.
16. Ricard, J.A., N. Tobiasson and A. Greatorex. 1976. The field assembled frost gage. Available from the library of the Corps of Engineers, U.S. Army, Cold Regions Research and Engineering Laboratory as a technical note, Hanover, NH. 10 p.
17. Flerchinger, G.N. 1991. Sensitivity of soil freezing simulated by the SHAW model. Trans. ASAE. 34:2381-2389.