EFFECT OF RESIDUE INVERSION ON SOIL MOISTURE CONSERVATION

By

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MOISTURE CONSERVATION

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INTRODUCTION

Six experiments were conducted to identify methods of reducing moisture evaporation in pots. The objective of this research was to evaluate the effect of inverting surface residues at different depths and residue rates on evaporative loss from different soils.

This thesis is presented in a format suitable for publication in the Soil Science Society of America Journal.

Effect of Residue Inversion on Soil Moisture Conservation

ABSTRACT

Soil moisture can be a limiting factor for dryland wheat production in Oklahoma. Six greenhouse experiments were conducted to determine the effect on moisture conservation of placing residue layers beneath the soil surface. Treatments included a control (no residue on the surface or inverted), 6 Mg ha^{-1} wheat straw placed 1.5, 3 and 6 cm below the surface, 6 Mg ha^{-1} applied on the surface (zero-tillage), 6 Mg ha^{-1} mixed with the surface 6 cm of soil (conventional tillage), 3 Mg ha^{-1} placed 6 cm below the surface, and 6 Mg ha^{-1} ground telephone book paper placed 1.5 cm beneath the surface. The soils used in the experiments were: 1) Teller fine-loamy, mixed, thermic, Udic Argiustoll; 2) Tillman fine, mixed, thermic, Typic Paleustoll; and 3) Cobb fine-loamy, mixed, thermic, Udic Haplustalf. Equal amounts of water were applied to all pots and evaporation was determined on a daily basis. Pots were placed in growth chambers where daytime and nighttime temperatures were ramped to 32°C and 18°C respectively. Evaporation losses in the first 10 days were greater in all residue inversion treatments when compared to zero-tillage. Evaporation losses stabilized after fifteen days in the 3

and 6 cm wheat straw inversion treatments while zero-tillage continued to show significantly high evaporative losses. The time required for evaporative losses to be equal for zero-tillage and 3 cm-6 Mg ha^{-1} wheat straw inversion treatments ranged from 11 to 25 days and was prior to the calculated wilting point for each soil. The 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had significantly lower evaporative losses as it approached the wilting point and offer promise for improving moisture conservation.

INTRODUCTION

Soil moisture stress can be a limiting factor for agricultural production in the Great Plains area (Unger, 1971a and Willis et al., 1963). Increasing soil moisture stress can decrease the concentration of N, P, and K in corn (Tisdale et al., 1985) and may reduce yield considerably (Hillel, 1982). Rosenberg et al.(1983), predicted that 90% or more of the precipitation in the Great Plains region can be lost via evaporation.

There are several ways to overcome soil moisture loss due to evaporation. Lemon (1956) noted that the greatest potential to decrease evaporative soil water loss was in decreasing turbulent transfer of water vapor to the atmosphere, decreasing capillary continuity and decreasing capillary flow and moisture holding capacity of soil surface layers. In two studies conducted by Miller (1969 and 1973), it was found that any kind of layer or profile discontinuity will decrease water movement compared with a uniform profile.

Several methods have been evaluated to reduce evaporation by placing different materials as layers on top of the soil surface. However, most have dealt with surface mulch for decreasing evaporation (Unger and Parker, 1968, Willis et al., 1957, Bond and Willis, 1971, Moody et al., 1963, Willis, 1962). Willis (1962) found that evaporation decreased as the amount of mulch and percentage of the surface covered were increased. Rosenberg et al. (1983)

classified mulching materials in two groups: in situ materials such as crop residue, and stubble mulch, and imported material such as plastic, stone, oil,etc. Work by Unger and Parker (1968) found that less water was lost when wheat straw was layered beneath the soil surface than when equal quantities of straw were mixed with the soil surface. However, this work which was conducted on a Pullman silty clay loam soil, demonstrated that surface applied wheat straw (zero-tillage) was more effective in decreasing evaporation losses than when layered beneath the surface. Further studies by Unger (1971a and 1971b) noted that gravel layers placed 5 cm beneath the soil surface reduced evaporation under laboratory conditions but that this practice interfered with deep-infiltration of water from rainfall when evaluated under field conditions. However, wheat straw inversion has not been extensively evaluated on different soils. The objective of this work was to evaluate the effect of inverting wheat straw and paper residue at different depths and rates on evaporative loss from three soil types.

MATERIALS AND METHODS

Three pilot studies using pots were conducted under controlled conditions. The first pilot study was conducted in an enclosed green house. Results of the pilot studies were used to design a final experiment evaluating the effect of residue inversion on moisture loss from three different soils. Treatment structure employed in the pilot studies is reported in Table 1. The 3 and 6 Mg ha^{-1} wheat straw rates were chosen to simulate average straw production where winter wheat is grown in the grain belt. The final experiment employed similar treatments in addition to the use of ground telephone book paper as an inverted layer treatment (Table 1). Paper was ground to pass a 1 mm screen and wheat straw was cut in segments approximately 5 cm in length.

For the pilot studies and final experiment, bulk surface soil (0-15 cm) was collected, allowed to dry, mixed thoroughly and ground to pass a 20 mesh screen. Selected properties of the soils used in all studies are listed in Table 2.

Replications, pot size, soil type, day and night temperatures, water added, percent soil moisture after water was added, and duration of each study are reported in Table 3. In the final study, pots were placed in the growth chamber for 3 days at 7°C and 99% humidity to assure water infiltration to the bottom of each pot, and to minimize evaporative loss prior to the time readings began. Prepared experimental units for the first pilot study were used again for study 2, whereby 1000 ml of water was applied to the same pots once all moisture had been depleted.

Variables evaluated included water evaporation and soil moisture distribution. Evaporation was determined based on total soil weight differences taking into account individual pot tare weights. Eight replications were employed in the final study in order to allow destructive sampling for profile moisture distribution within each pot. Two of the eight replications were destructively sampled at 10, 16, 23 and 39 days for Tillman silty clay; 10, 15, 22 and 39 days for Teller sandy loam; and 10, 25, 32 and 39 days for Cobb sandy loam. The four sampling dates were chosen to simulate: 1) the time when soil moisture loss was the same in zero-tillage and the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment; 2) approximately 7 days prior to and after this occurred; and 3) 39 days after water was applied to all soils. Predicted dates for destructive sampling were based on observations made in the pilot studies. Soil moisture was determined at 3 cm increments in each pot by the destructive sampling and profile moisture distribution was plotted accordingly. In the second study, soil moisture was only measured at the time when the 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage treatments had lost approximately the same amount of water.

Plants were not allowed to grow in any of the pots in order to maintain evaporative loss uniformity. In all experiments, pots were weighed daily until all moisture had been lost in the check treatment (no wheat straw incorporated or placed on the surface).

A randomized complete block design was used for all experiments. Analysis of variance on cumulative evaporation was performed by individual date and single degree of freedom non-orthogonal contrasts were used to detect statistical differences between treatments. Analysis of variance on soil moisture distribution from the destructive sampling was performed using depth as the split variable. The standard error of the difference (SED) between two means using the overall error term was calculated and is reported on the moisture distribution graphs.

RESULTS

Pilot Studies

Analysis of variance for pilot studies by date is reported in Tables 4, 5 and 6, respectively. Graphs of cumulative evaporation loss from the same experiments is illustrated in Figure 1.

Evaporative losses in all treatments were high in the first 1 to 7 days of all experiments (Figure 1). This agrees with work by Lemon (1956) who found that evaporation is high in early stages since it is controlled by external conditions. From 7 to 11 days, evaporative losses continued, but at much lower rates. After 11 days, evaporative losses were substantially lower in all treatments excluding zero-tillage (Figure 1). With few exceptions, evaporation rates (kg water/day) were somewhat constant in the zero-tillage treatment (0-30 days). Alternatively, surface inversion treatments lost water at greater rates early in the experiments (0-7 days) and then had constant evaporation rates much less than that of zero-tillage (Figure 1). High initial evaporation rates in all experiments for the wheat straw inversion treatments (0-7 days) were most probably due to the surface layer losing water at much greater rates than was found in zero-tillage.

It was interesting to find that the 6 Mg ha^{-1} surface incorporation of wheat straw treatment (simulation of conventional tillage) lost moisture at the same relative rate as the check where no wheat straw was applied in all experiments. This would suggest that there is no advantage of incorporating wheat straw compared to removing the straw (check) in terms of moisture loss.

Once the surface soil on top of the inverted wheat straw layer had dried out, further subsurface soil moisture losses were reduced by this discontinuity. It is important to note that when total evaporative loss (kg water) was equal from the zero-tillage and 3 cm-6 Mg ha^{-1} wheat straw inversion treatments (24, 11, and 12 days for the three pilot studies), the wilting point had not yet been reached. The distribution of moisture in the soil profile is presented in Figure 2. Because evaporation proceeded much more slowly beyond this time (when moisture losses were equal between these two treatments), moisture was being conserved in the wheat straw inversion treatment.

Analysis of variance performed on select dates for estimated water loss is reported in Tables 4-6 for the pilot studies. After 24, 11 and 12 days the 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage treatments had lost the same amount of water in studies 1, 2, and 3, respectively. This was noted in the lack of significant differences in the single degree of freedom contrasts (3cmI-6 vs ZT-6, Tables 4-6). However, following this time period the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had significantly lower total water losses when compared to zero-tillage at the same straw rates (Tables 4-6). At the completion of each experiment, the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had lost 69 to 78 % of the water added, while, the zero-tillage treatment lost in excess of 95% in all experiments. This difference in water loss between the 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage treatments was significant in all experiments (Tables 4-6).

The time (days) when the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had lost less total water compared to zero-tillage was different for pilot studies 1, 2 and 3. This took place at 24 days in study 1; whereas in the growth chamber (study 2 and 3) this was at 11 and 12 days, respectively. This difference between the growth chamber and the greenhouse was considered to be a function of humidity and wind speed. Also, this could suggest that the 3 cm-6 Mg ha^{-1} wheat straw inversion could be more effective in areas where soil evaporative rates are greater. Total water loss savings in the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment compared to zero-tillage, would need to be observed prior to reaching a soils wilting point.

When moisture losses were the same for the 3 cm-6 Mg

ha^{-1} wheat straw inversion and zero-tillage (24, 11 and 12 days for studies 1, 2 and 3), the soil moisture content was 14.1%, 13.0% and 15.9% in these same experiments. Because the wilting point for these soils was less than that observed above, these results suggest a total water loss advantage for wheat straw inversion practices.

Final Studies

Analysis of variance for estimated water loss from this experiment by date is reported in Tables 7, 8 and 9. Graphs of cumulative evaporation loss for the same experiments is presented in Figure 3. The final experiment compared three different soil textures. Treatments 1, 2, 3 and 6 were the same in all experiments. However, 6 Mg ha^{-1} wheat straw inversion treatments placed closer to the surface (1.5 cm) were substituted for the 6 cm inversion treatments in the pilot studies because of the high evaporation losses (Table 1).

Evaporative losses in all treatments were high in the first 1 to 10 days (Figure 3). This was similar to that observed in the pilot studies. From 10 to 25 days, evaporative losses continued, but at much lower rates. After 25 days, evaporative losses were substantially lower in all treatments excluding zero-tillage (Figure 3). With few exceptions, evaporation rates (kg water/day) were somewhat constant in the zero-tillage treatment (0-25 days). Alternatively, wheat straw inversion treatments lost water at greater rates early in the experiments (0-10 days) and then had constant evaporation rates much less than that of zero-tillage (Figure 3).

After 16, 15 and 25 days the 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage treatments had lost the same amount of water. Following this time period the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had significantly lower total water losses when compared to zero-tillage at the same wheat straw rates (Tables 7-9). At the end of the experiment, the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment had lost 68, 82 and 92% of the water added, while, the zero-tillage treatment had lost of 81, 95 and 92% of the water added in the three soils. This difference in water loss between 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage was significant in all soils excluding the Cobb sandy clay loam soil. This is somewhat consistent with work by Unger and Parker (1968) who found that surface applied residues (zero-tillage) reduced total evaporation losses when compared to residue inversion on a similar clay loam soil. Analogous to this study, Unger and Parker inverted the wheat straw at 3 cm. However, they used an 11 Mg ha^{-1} wheat straw rate which is almost twice that which would be produced from a single season wheat crop and they evaluated wheat straw inversion on only one soil. It was therefore important to find that the residue inversion treatments were successful in conserving moisture (compared to zero-tillage) on the silty clay and sandy loam soils at much lower wheat straw rates.

The point at which wheat straw inversion treatments had lost less total water compared to zero-tillage was different for each soil. This took place at 16 days in Tillman soil, 15 days for Teller soil and 25 days for Cobb soil. Unlike results from the silty clay and sandy loam soils, surface inversion treatments evaluated on the sandy clay loam soil failed to produce any kind of discontinuity in evaporation with time (Figure 3).

Zero-tillage had significantly more moisture in the profile at all depths in all three soils after 10 days (Figure 4). When total moisture loss was the same in the 3 cm-6 Mg ha^{-1} wheat straw inversion and zero-tillage treatments (16, 15 and 25 days, experiments 4, 5 and 6), the 3 cm-6 Mg ha^{-1} wheat straw inversion had increased moisture at all depths beneath the inversion layer (Figure 5). The exception to this was noted in the Cobb sandy clay loam soil. Destructive profile sampling for the two ensuing dates showed increased moisture at lower depths for the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment when compared to zero-tillage in all three soils (Figures 6 and 7).

Infiltration Rate

Analysis of variance and contrasts for water infiltration measured at the time each experiment was initiated is reported in Table 10 for final study. Infiltration was not measured in the pilot studies.

Infiltration rates in wheat straw inversion treatments were much lower compared to zero-tillage and/or check treatments (Tables 10). This was due to the presence of the inverted layer which was expected to inhibit the wetting front. The highest infiltration rate was found when wheat straw was surface incorporated (SI-6) and the lowest for the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment (3cmI-6) in experiments 4, 5 and 6 (Table 10).

DISCUSSION

Zero-Tillage vs Residue Inversion

The depth at which wheat straw was inverted beneath the surface had significant effects on water loss. In the first 12 days of each experiment, zero-tillage lost less water compared to all other treatments. However, after 12 days the 3 cm-6 Mg ha^{-1} wheat straw inversion treatment appeared to be superior. Once it was found that 3 cm-6 Mg ha^{-1} wheat straw inversion was superior to 6 cm-6 Mg ha^{-1} (pilot studies), moving the inverted wheat straw closer to the surface was attempted. However, in the final study, 3 cm-6 Mg ha^{-1} wheat straw inversion was superior to 1.5 cm-6 Mg ha^{-1} in terms of water loss. This could be due to the straw being too close to the surface at 1.5 cm, therefore being more like zero-tillage where capillary movement was not affected. The 6 cm wheat straw inversion treatment evaluated in the pilot studies had significantly greater water loss when compared to 3 cm at the same wheat straw rate. It is important to note that these same results may not be observed in the field where the subsurface soil volume would be much greater than what was present in the pots used here. These results suggest that the 3 cm-6 Mg ha^{-1} wheat straw inversion could be more effective in areas where soil evaporative rates are greater.

In addition, it was found that the 6 Mg ha^{-1} wheat straw rate was superior to that of 3 Mg ha^{-1} when inverted 6 cm beneath the surface in the pilot studies in terms of moisture conservation. However, all of the wheat straw inversion treatments had significantly lower infiltration rates which would not be acceptable on a larger scale unless employed in arid regions. It is highly likely that these practices could result in high surface soil erosion in humid regions whereby the residue inversion layer could act as a pseudo lithic contact.

Use of Paper

Utilizing paper as a source of residue employing the inversion methods in this study did not decrease water losses when compared to zero-tillage and wheat straw inversion. The failure of this source to perform the same as wheat straw inverted beneath the surface was most probably due to the excessive fineness employed. The capillary contact was apparently not broken when using finely ground paper. Future studies will need to evaluate the use of paper at much coarser grinds.

Differences Among Soils

Evaporation losses were markedly different in the three soils evaluated. At the time readings were terminated, the sandy clay loam soil had significantly less moisture in the entire profile. Water losses were much greater in this soil over the same time period which could be the reason why such extreme differences were noted between treatments (zero-tillage and 3 cm-6 Mg ha^{-1}) when compared to the other soils (Figure 7). It is not understood why the residue inversion treatments were not as effective in conserving moisture in the Cobb sandy clay loam soil as compared to the Tillman silty clay and Teller sandy loam soils. Excluding Cobb sandy clay loam, a greater percentage of the total soil moisture was found in the surface horizon (3 cm) for zero-tillage and just beneath the wheat straw inversion layer for the 3 cm-6 Mg ha^{-1} treatment at the first two destructive sampling dates (Figures 4 and 5). For the last two destructive sampling dates, a larger percentage of the total moisture continued to be found just beneath the wheat straw inversion layer (3 cm-6 Mg ha^{-1}), while the zero-tillage treatment no longer mirrored this effect (Figures 6 and 7). The exception to this was again noted on the sandy clay loam soil (Figures 6 and 7). Similar to the work by Unger (1968), there was apparently no benefit of using residue inversion when compared to zero-tillage on a sandy clay loam soil. Although the Cobb sandy clay loam soil contained less silt than the other two soils, it is difficult to ascertain why this might have affected treatment response. Other factors that could be considered would be soil thermal properties and heat processes that could have caused variable evaporative losses when employing straw inversion practices.

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Table 1. Treatments used to evaluate effect of residue management on soil moisture loss.

Description of the treatments	Codes
A. Pilot Studies	
1. Check (no residue)	Check
2. Wheat straw, zero-tillage, 6 Mg ha^{-1}	ZT-6
3. Wheat straw surface incorporated, 6 Mg ha^{-1}	SI-6
4. Wheat straw, 6 cm inversion, 6 Mg ha^{-1}	6cmI-6
5. Wheat straw, 6 cm inversion, 3 Mg ha^{-1}	6cmI-3
6. Wheat straw, 3 cm inversion, 6 Mg ha^{-1}	3cmI-6
B. Final Study	
1. Check (no residue)	Check
2. Wheat straw, zero-tillage, 6 Mg ha^{-1}	ZT-6
3. Wheat straw surface incorporated, 6 Mg ha^{-1}	SI-6
4. Wheat straw, 1.5 cm inversion, 6 Mg ha^{-1}	1.5cmI-6
5. Ground paper, 1.5 cm inversion, 6 Mg ha^{-1}	1.5cmP-6
6. Wheat straw, 3 cm inversion, 6 Mg ha^{-1}	3cmI-6

Table 2. Soil characteristics used for pilot studies and final experiment.

Properties	Tillman	Teller	Cobb
Texture	sic	sl	scl
Clay, %	45.22	13.12	28.31
Silt, %	40.65	20.63	5.40
Sand, %	14.13	65.25	66.29
Bulk density, g cm^{-3}	1.45	1.67	1.58
Organic carbon, %	0.80	1.10	0.39
N-total, %	0.06	0.75	0.04
C:N	12.70	14.34	11.14
Volumetric water content, %			
-15 bars	15.25	6.82	6.67
saturation	45.20	38.10	41.50

sl= sandy loam
sic= silty clay
scl = sandy clay loam

Table 3. Replications, pot size, type of soil, temperature and amount of water added for all experiments.

Properties	pilot studies			Tillman	Teller	Cobb
Replications	3	3	3	8	8	8
Pot Size, l	4	4	6	5	5	5
Soil	UA	UA	UA	TP	UA	UH
Soil per pot, g	5620	5620	4950	4495	4785	4670
Day time temp,°C	30	31	31	31	31	31
Night time temp, °C	17	18	18	18	18	18
Water added, ml	1000	1000	1000	2034*	1823*	1941*
Soil moisture, %@	30	30	34	66	64	66
Time, days	41	30	30	39	39	39
Wilting point, %	7	7	7	15	7	7

UA - Teller fine-loamy, mixed, thermic Udic Argiustoll
TP - Tillman fine, mixed, thermic Typic Paleustoll
UH - Cobb fine-loamy, mixed, thermic Udic Haplustalf
@ - soil moisture after water was added
* - water required for saturation

Table 4. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, study 1.

		Days after water was applied			
		3	24	34	41
Source	df	Mean Squares			
Rep	2	0.0019	0.0006	0.0008	0.0009
Trt	5	0.0132**	0.0773**	0.0472**	0.0406**
Error	10	0.0029	0.0012	0.0013	0.0011
CV (%)		8	5	4	4
Contrasts:		Cumulative evaporation difference, kg			
3cmI-6 vs ZT-6	1	0.164**	-0.0027	-0.1647**	-0.1947**
6cmI-6 vs ZT-6	1	0.171**	0.1987**	0.0073	-0.0420
SI-6 vs ZT-6	1	0.123**	0.3060**	0.1327*	0.0827
3cmI-6 vs 6cmI-6	1	-0.007	-0.2013**	-0.1720**	-0.1527**
3cmI-6 vs SI-6	1	0.041*	-0.3087**	-0.2973**	-0.2773**
6cmI-6 vs SI-6	1	0.048**	-0.1073**	-0.1253**	-0.1247**

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 5. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, study 2.

		Days after water was applied			
		3	11	14	30
Source	df	Mean Squares			
Rep	2	0.0047	0.0005	0.0004	0.0007
Trt	5	0.0384**	0.0881**	0.0709**	0.0734*
Error	10	0.0013	0.0058	0.0061	0.0097
CV (%)		9	10	10	9
Contrasts:		Cumulative evaporation difference, kg			
3cmI-6 vs ZT-6	1	0.254**	-0.021	-0.127	-0.411**
6cmI-6 vs ZT-6	1	0.295**	0.128	0.007	-0.376**
SI-6 vs ZT-6	1	0.214**	0.333**	0.233**	-0.133
3cmI-6 vs 6cmI-6	1	-0.041	-0.149*	-0.134	-0.035
3cmI-6 vs SI-6	1	0.040	-0.353**	-0.360**	-0.278**
6cmI-6 vs SI-6	1	0.081*	-0.203**	-0.226**	-0.243*

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 6. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, study 3.

		Days after water was applied			
		3	12	14	30
Source	df	Mean Squares			
Rep	2	0.0010	0.0008	0.0010	0.0006
Trt	5	0.0498**	0.0455**	0.0375**	0.0299**
Error	10	0.0018	0.0012	0.0014	0.0007
CV (%)		11	5	4	3
Contrasts:		Cumulative evaporation difference, kg			
3cmI-6 vs ZT-6	1	0.301**	-0.015	-0.063	-0.191**
6cmI-6 vs ZT-6	1	0.333**	0.149**	0.067	-0.114**
SI-6 vs ZT-6	1	0.288**	0.265**	0.195**	-0.054**
3cmI-6 vs 6cmI-6	1	-0.033	-0.135**	-0.130**	-0.076*
3cmI-6 vs SI-6	1	0.013	-0.251**	-0.259**	-0.245**
6cmI-6 vs SI-6	1	0.045	-0.116**	-0.129**	-0.169**

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 7. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, Tillman sic.

		Days after water was applied			
		10	16	23	39
Source	df	Mean Squares			
Rep	1	0.0123	0.0054	0.0025	0.0004
Trt	5	0.0743**	0.0641**	0.0505**	0.0372*
Error	5	0.0043	0.0065	0.0050	0.0015
CV (%)		5	6	5	2
Contrasts:		Cumulative evaporation difference, kg			
ZT-6 vs SI-6	1	-0.451**	-0.329**	-0.159	-0.028
ZT-6 vs 3cmI-6	1	-0.189*	-0.007	0.183*	0.283**
1.5cmI-6 vs 3cmI-6	1	0.024	0.071	0.136	0.218**
1.5cmP-6 vs 3cmI-6	1	0.225*	0.284*	0.335**	0.331**
ZT-6 vs 1.5cmI-6	1	-0.213*	-0.079	0.047	0.065
SI-6 vs 3cmI-6	1	0.262**	0.322**	0.342**	0.312**

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 8. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, Teller sl.

		Days after water was applied			
		10	15	22	39
Source	df	Mean Squares			
Rep	1	0.0103	0.0059	0.0033	0.0005
Trt	5	0.0537**	0.0430*	0.0327*	0.0218*
Error	5	0.0034	0.0048	0.0056	0.0026
CV (%)		4	5	5	3
Contrasts:		Cumulative evaporation difference, kg			
ZT-6 vs SI-6	1	-0.333**	-0.263**	-0.070	-0.011
ZT-6 vs 3cmI-6	1	-0.156*	0.018	0.235*	0.253**
1.5cmI-6 vs 1.5cmP-6	1	-0.200*	-0.195*	-0.165	-0.073
1.5cmI-6 vs 3cmI-6	1	0.023	0.063	0.120	0.178*
ZT-6 vs 1.5cmI-6	1	-0.179*	-0.045	0.115	0.075
SI-6 vs 3cmI-6	1	0.177*	0.281**	0.305**	0.264**

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 9. Analysis of variance and single degree of freedom contrasts for evaporation (kg) at selected dates, Cobb scl.

		Days after water was applied			
		10	25	32	39
Source	df	Mean Squares			
Rep	1	0.1003*	0.0086*	0.0045	0.0030*
Trt	5	0.0973*	0.0123**	0.0047*	0.0025*
Error	5	0.0125	0.0008	0.0008	0.0005
CV (%)		8	2	2	1
Contrasts:		Cumulative evaporation difference, kg			
ZT-6 vs SI-6	1	-0.377*	-0.176**	-0.099*	-0.071*
ZT-6 vs 3cmI-6	1	-0.457**	-0.046	0.008	0.012
1.5cmI-6 vs 3cmI-6	1	0.004	0.083*	0.067	0.050
1.5cmP-6 vs 3cmI-6	1	0.124	0.134**	0.100*	0.073*
ZT-6 vs 1.5cmI-6	1	-0.461**	-0.129**	-0.059	-0.038
SI-6 vs 3cmI-6	1	0.081	0.130**	0.107**	0.083**

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

Table 10. Analysis of variance and single degree of freedom contrasts for infiltration (cm hr^{-1}) from final study.

Source	df	Mean Squares Tillman	Teller	Cobb
Rep	1	0.0048	0.0005	0.0085
Trt	5	0.0285*	0.0976**	0.0670**
Error	5	0.0042	0.0015	0.0034
CV (%)		14	6	7
Contrasts:		Infiltration rate difference, cm hr^{-1}		
ZT-6 vs SI-6	1	-0.1600	-0.0600	-0.0200
ZT-6 vs 3cmI-6	1	0.2000*	0.4600**	0.4000**
1.5cmI-6 vs 3cmI-6	1	0.2200*	0.3200**	0.2000*
1.5cmP-6 vs 3cmI-6	1	0.1600	0.0200	0.0600
ZT-6 vs 1.5cmI-6	1	-0.0200	0.1400*	0.2000*
SI-6 vs 1.5cmI-6	1	0.1400	0.2000**	0.2200**
SI-6 vs 3cmI-6	1	0.3600**	0.5200**	0.4200**
1.5cmP-6 vs check	1	-0.2000*	-0.3400**	-0.3400**
Infiltration rate (cm hr^{-1})				
Check		0.6200	0.7200	1.0200
ZT-6		0.4600	0.8200	1.0200
SI-6		0.6200	0.8800	1.0400
1.5cmI-6		0.4800	0.6800	0.8200
1.5cmP-6		0.4200	0.3800	0.6800
3cmI-6		0.2600	0.3600	0.6200

*, ** - significant at the 0.05 and 0.01 probability levels, respectively

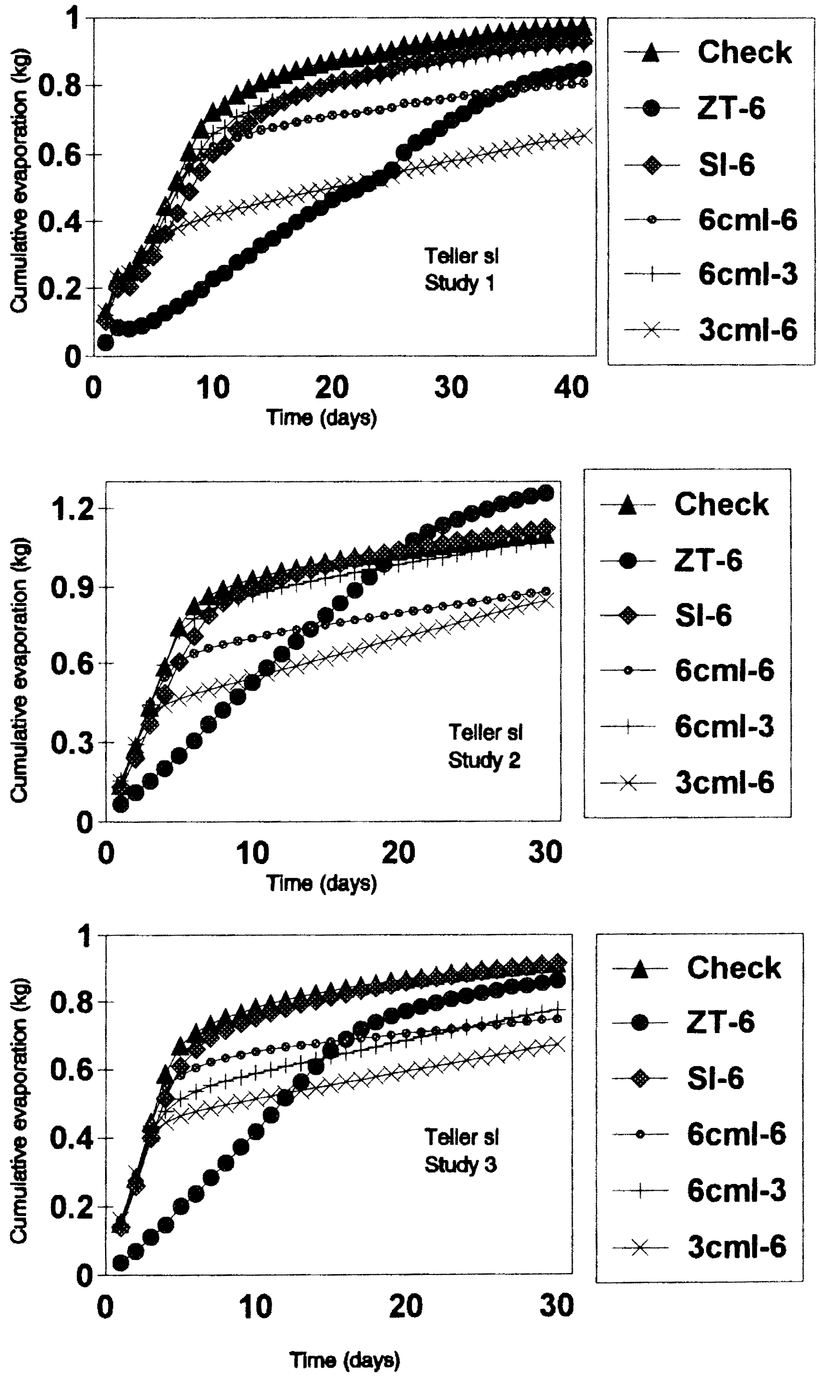


Figure 1. Cumulative evaporation with time from pilot studies

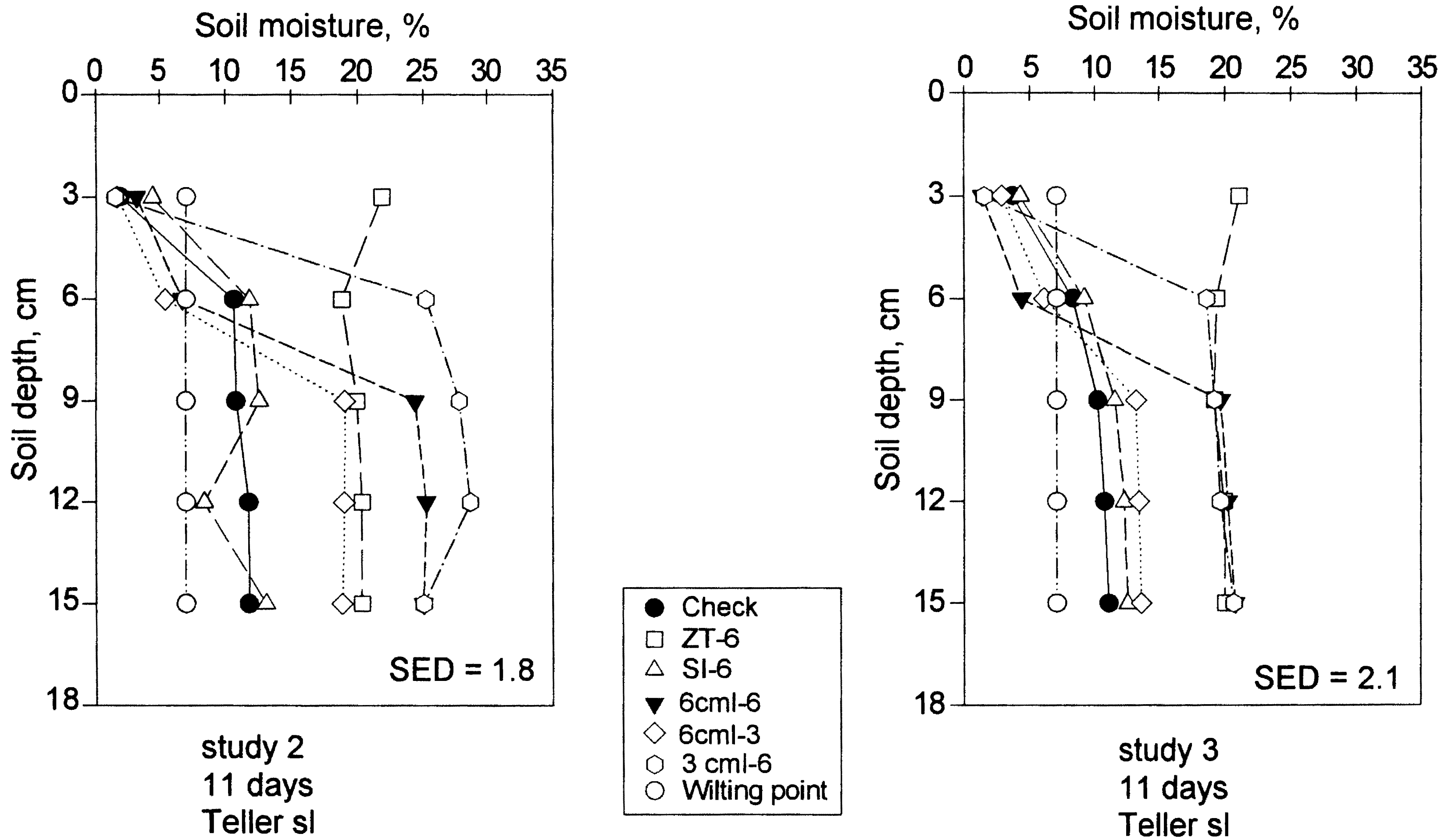


Figure 2. Soil moisture distribution by depth when evaporative losses were approximately the same for zero-tillage and the 3 cm-6 Mg ha-1 wheat straw inversion treatment for pilot studies.

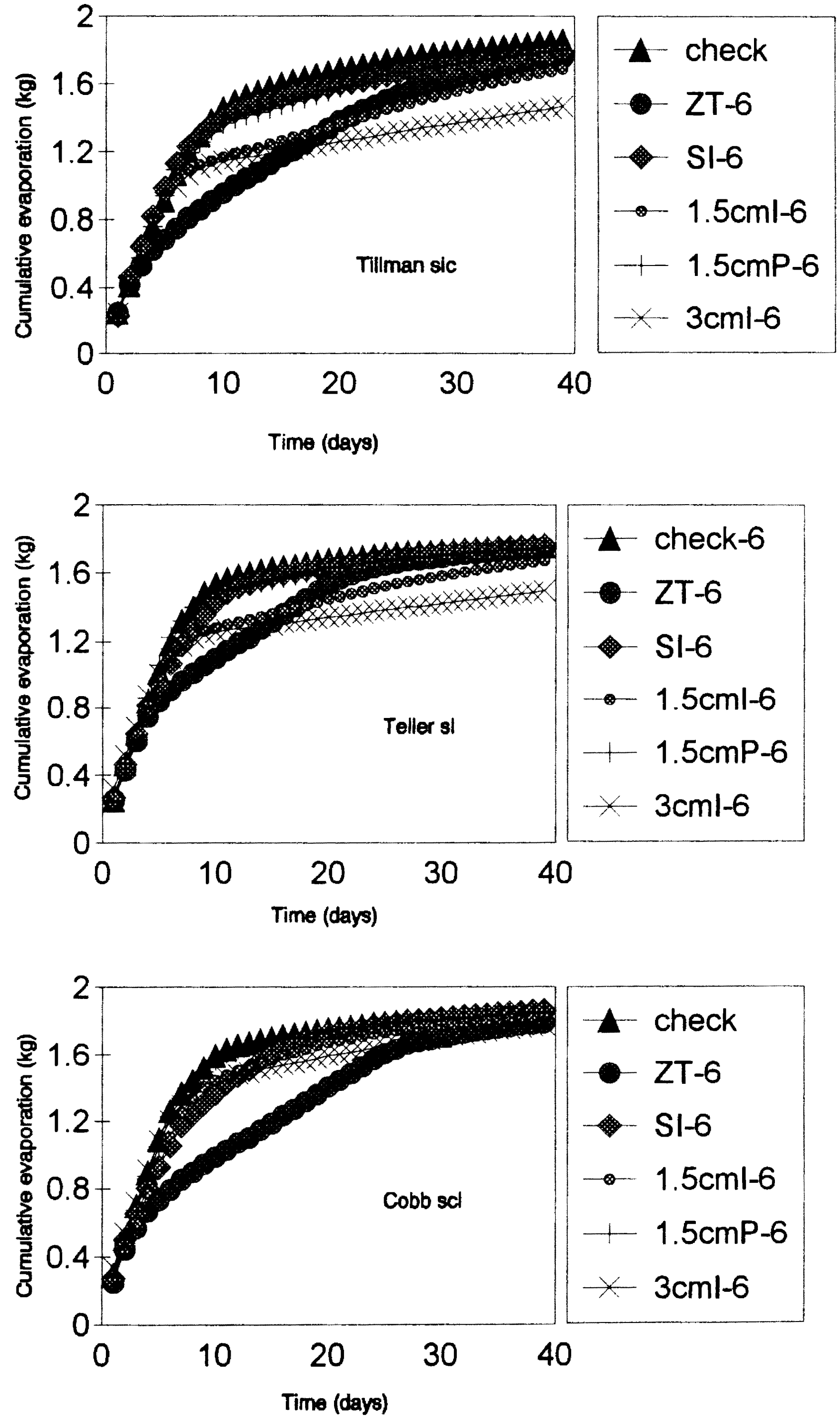
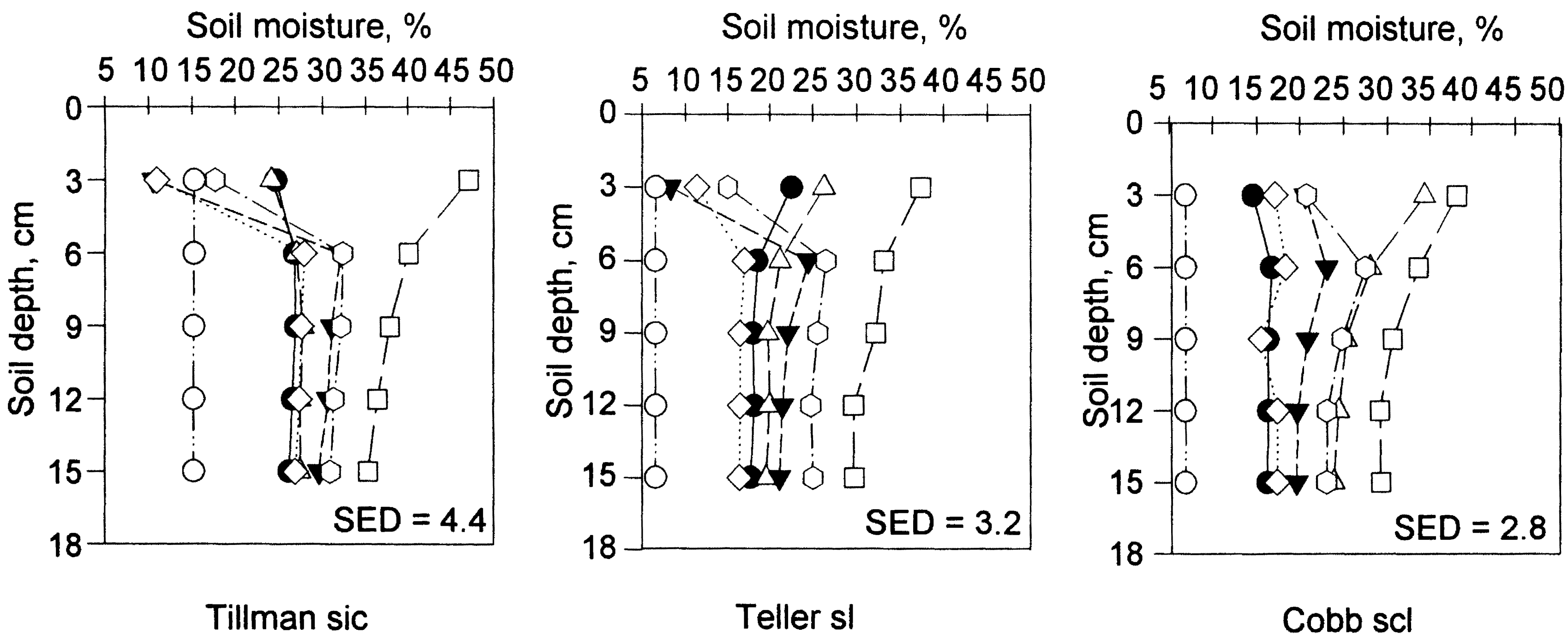


Figure 3. Cumulative evaporation with time from final study



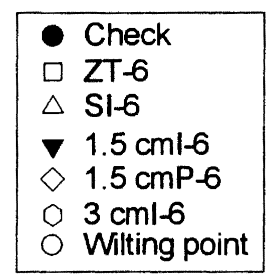


Figure 4. Soil moisture distribution by depth after 10 days of evaporative losses in three different soils

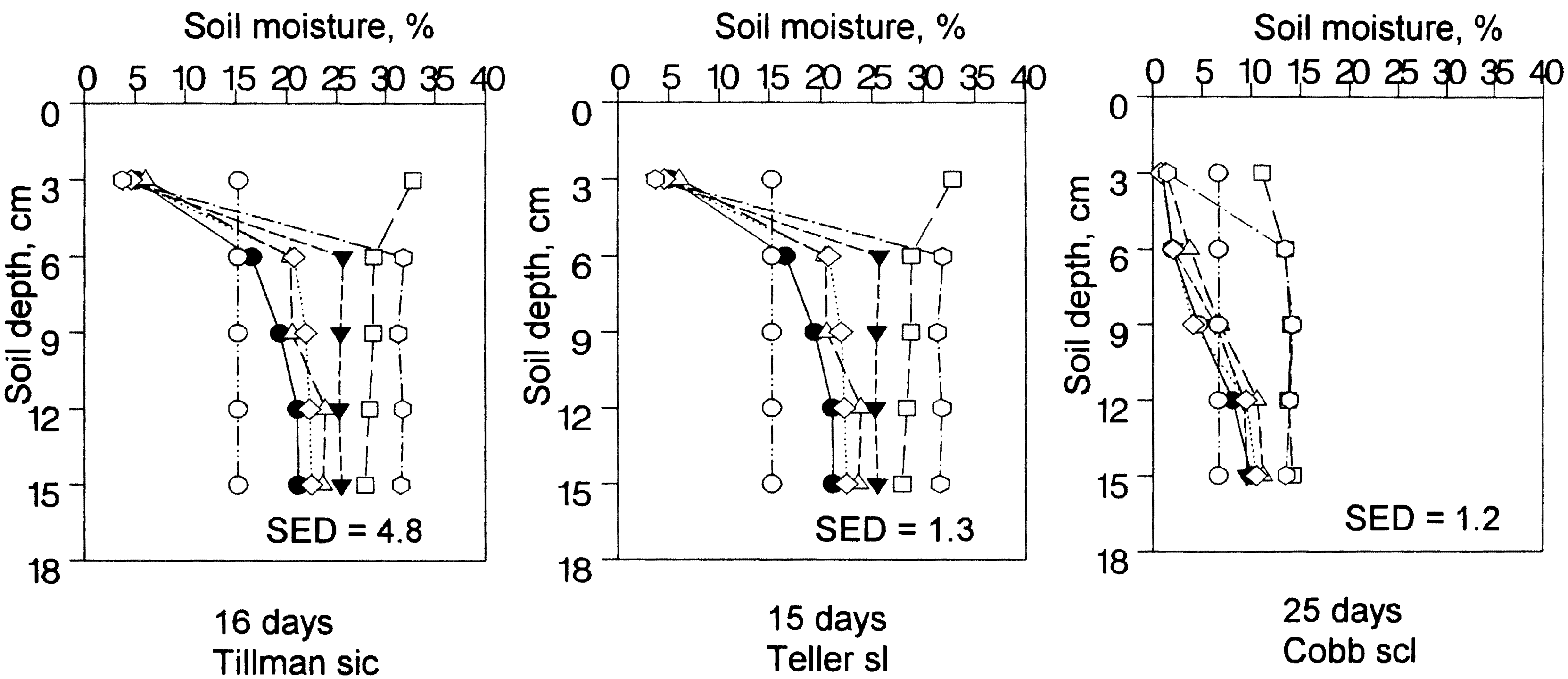
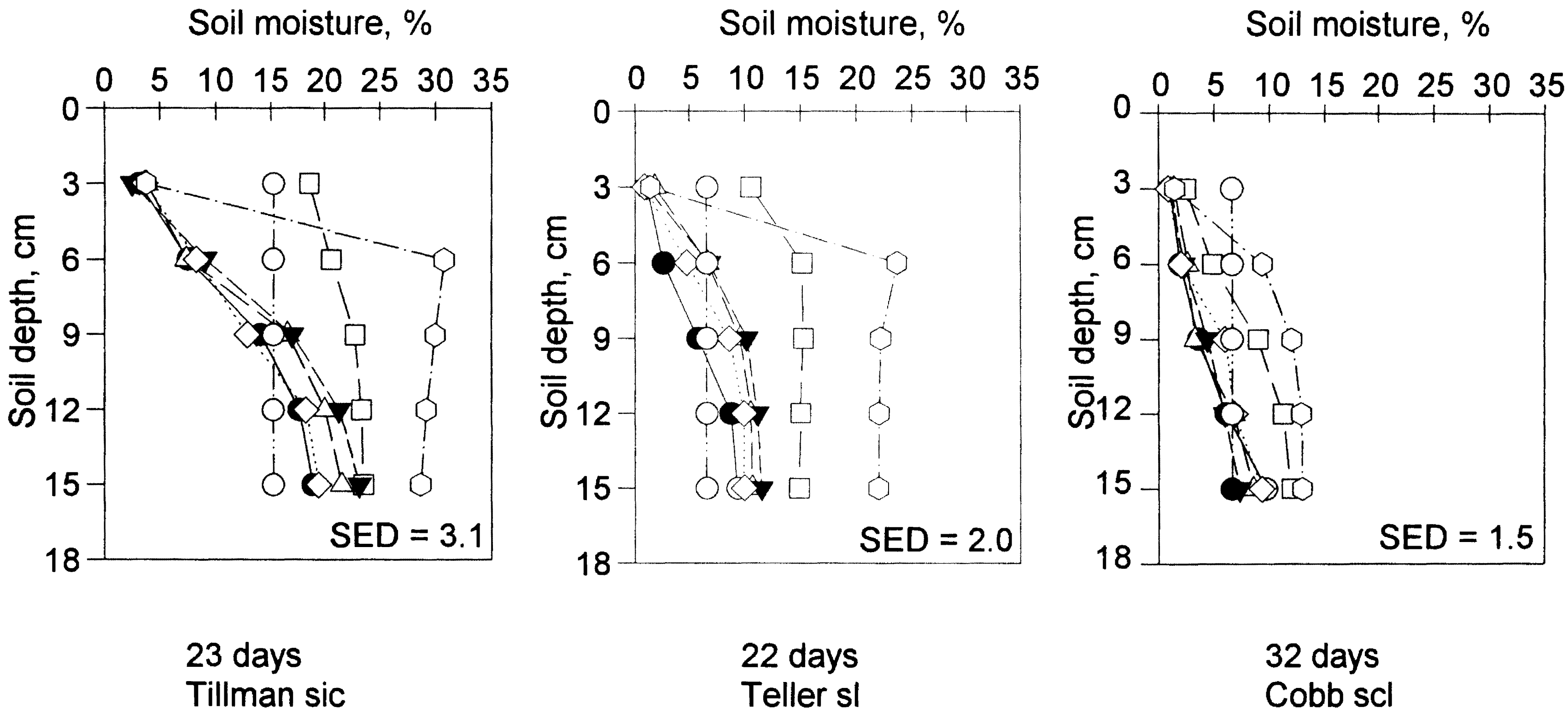


Figure 5. Soil moisture distribution by depth when total evaporative losses were approximately the same for zero-tillage and the 3 cm-6 Mg ha-1 wheat straw inversion treatment for three soils.



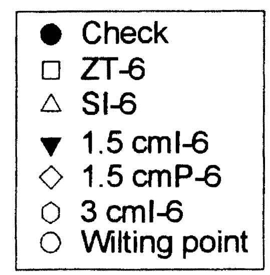


Figure 6. Soil moisture distribution by depth, seven days after the time evaporative losses were equal in zero-tillage and the 3 cm-6 Mg ha-1 wheat straw inversion treatment for three soils

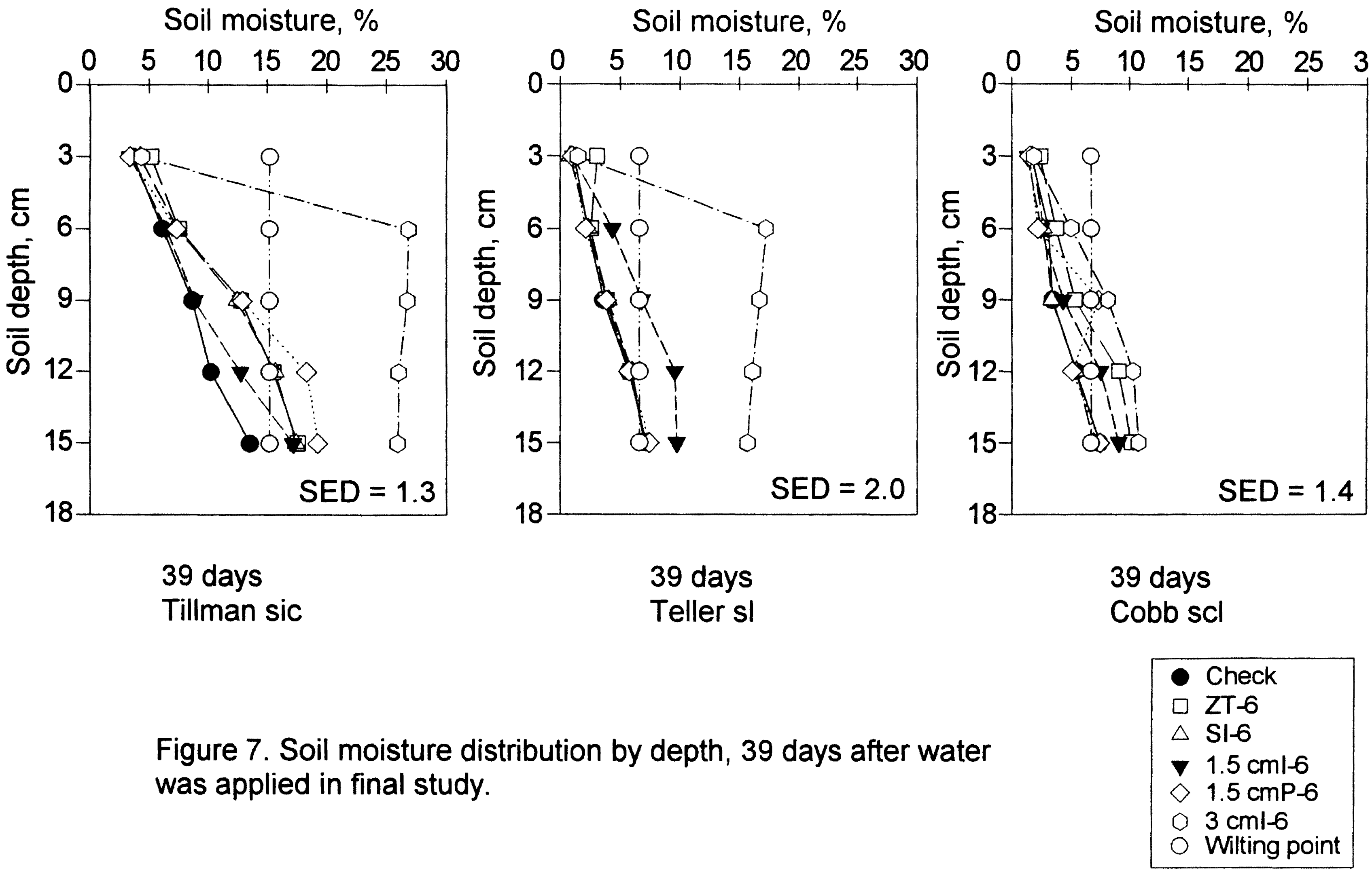


Figure 7. Soil moisture distribution by depth, 39 days after water was applied in final study.

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