Water retention of soft sedimentary siltstone fragments
by James Peter Ruddell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Soils
Montana State University

Abstract:
A method was developed and tested to determine water retention characteristics of soft sedimentary siltstone commonly found underlying shallow soils in southeastern Montana. Siltstone fragments were excavated from a Cabbart soil, coated with saran, and brought to the laboratory to measure moisture contents from saturation at 0 MPa potential, to permanent wilting at -1.5 MPa potential. Results indicate that siltstone fragments can be a source of plant available water. The fragments averaged 0.10 cm of plant available water per cm of siltstone when field capacity was defined as -.010 MPa.

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James Peter Ruddell

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A method was developed and tested to determine water retention characteristics of soft sedimentary siltstone commonly found underlying shallow soils in southeastern Montana. Siltstone fragments were excavated from a Cabbart soil, coated with saran, and brought to the laboratory to measure moisture contents from saturation at 0 MPa potential, to permanent wilting at -1.5 MPa potential. Results indicate that siltstone fragments can be a source of plant available water. The fragments averaged 0.10 cm of plant available water per cm of siltstone when field capacity was defined as -.010 MPa.

INTRODUCTION

Shallow soils over soft beds of sedimentary siltstone are common throughout southeastern Montana. Traditionally the soft bedrock has been ignored as a source of plant available water. Proponents of farming these shallow soils believe that the soft rock underlying the soil has water retention characteristics similar to the soil above.

Successful dryland crop yields are often determined by the amount of plant available water supplied by growing season precipitation and stored soil water (Kresge and Halvorson, 1979). Because the semi-arid climates seldom provide adequate growing season precipitation, stored soil water must make up the difference. Stored soil water is that amount stored in the root zone that is available to the plant, and is often considered to be the water held between field capacity, -.010 to -.033 MPa* potential, and permanent wilting percentage, -1.5 MPa potential (Soil Survey Staff, 1951).

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*MPa (megapascals): International standard unit that has replaced bar and atmosphere. To convert bar and atmosphere to MPa, multiply by 0.10. That is, bar or atmosphere becomes 1.5 MPa.

The Soil Conservation Service (SCS) Soil Survey Staff (1987) describe pressure plate extraction methods for determining the amount of soil water held between -.033 and -1.5 MPa. Commonly, crushed and sieved samples are placed in retainer rings on a porous plate. Field capacity (-.033 MPa) and wilting percentage (-1.5 MPa) pressures are applied until equilibrium is obtained, and plant available water calculated.

Another approach is to coat soil clods with saran, a plastic coating, so that field structure is maintained. A patch of the coating is removed from the bottom and top of flat surfaces of the clod and the clod is placed on a porous plate. Field capacity and wilting percentage pressures are applied until equilibrium is obtained and plant available water calculated.

The purpose of this study was to develop and test a method for estimating the amount of plant available water in soft rock. The results will improve calculations of stored water available for plant growth in soils that contain similar soft rock fragments.

LITERATURE REVIEW

Water Retention

Plant available water is the amount of water a soil can hold between field capacity and the permanent wilting percentage. Veihmeyer and Hendrickson (1931), defined field capacity as the amount of water a field soil will hold against the force of gravity. Water in excess of field capacity usually drains within two or three days, depending on pore space arrangement and size.

Veihmeyer and Hendrickson (1949), used sunflower plants grown in small containers to determine when plant leaves permanently wilt due to a deficiency of soil water. At permanent wilting the leaves do not recover in a saturated atmosphere without the addition of water to the soil. The authors concluded that the permanent wilting percentage (often shortened to wilting point), occurs within a small range of soil moisture tensions and is fairly constant.

SCS Soil Survey Staff (1967) use the term water retention to describe the amount of water a soil can hold between field capacity and wilting point. In the past this was referred to as available water capacity. The term water retention will be used in this paper so that results are compatible with soil survey interpretations.

Measuring Water Retention

Water retention is based on the energy status of soil water which determines the direction of flow and the amount available for plant growth. The energy status of water is dependent primarily on matric potential, a function of pore size and arrangement, and osmotic potential, a function of soluble salt concentration. The following studies emphasize the energy status of water as it is affected by matric potential.

Richards and Weaver (1943), used a pressure plate apparatus to compare field wilting point with water retained at -1.5 MPa potential. Most of the soils tested had field wilting points that correspond with -1.5 MPa.

Richards and Weaver (1944), again used a pressure plate apparatus to show that water retained by soil samples at -.033 MPa generally corresponds with field capacity. Their results also indicated that coarse textured soils retain more water, by weight, then do fine textured soils at the same potential. Jamison (1956), in a review of literature, stated that field capacity for most soils varies between -.02 and -.05 MPa potential, with coarser textured soils closer to -.02 MPa and finer textured soils closer to -.05 MPa.

In the previous studies, water retention was measured with samples that were disturbed, ground and screened through a 2 mm sieve, destroying pore space arrangement. The following studies compare disturbed samples with undisturbed samples in which pore space arrangement is still intact.

Salter and Williams (1965), compared water retention measurements of undisturbed soil cores with disturbed samples at -.033 and -1.5 MPa potential. Disturbed and undisturbed samples retained about the same amount of moisture at -1.5 MPa potential. However, disturbed samples retained less water than undisturbed samples when both were at -.033 MPa potential. They concluded that water retention measurements on undisturbed samples are more representative of field conditions.

Young and Dixon (1966) also compared -.033 MPa water content of disturbed and undisturbed soil samples. Natural clods were coated with saran, a flexible plastic. The volume of the coated clod was obtained by water displacement. A patch of the saran coating on the bottom and the top of the clod was removed to allow free flow of water. The clod was placed in the pressure plate apparatus and brought to equilibrium at -.033 MPa potential. Results indicate that estimates are more reliable for undisturbed samples than for disturbed samples.

Soft Sedimentary Bedrock

Partly consolidated sandstone, siltstone and shale comprise the soft sedimentary bedrock that commonly occurs in Cr horizons of southeast Montana. The Soil Survey Manual (Soil Survey Staff, 1951) describes the Cr horizon as a mineral layer of soft bedrock. This includes beds of partially consolidated sandstone, siltstone and shale that are soft enough to be dug with a spade, but have a high enough bulk density that roots cannot penetrate.

A paralithic contact is the contact between soil and the soft rock. Rock fragments near the paralithic contact are usually in fissile layers (several mm in thickness) with soil fines between them. With depth the fragments become thicker (up to 4 cm) with fewer fines between them.

Recognition of a paralithic contact is difficult because the soil horizon immediately above it often has similar color, texture, and bulk density compared to material below it. Identification is most often made in a soil pit by observing the bedding planes of the soft bedrock and the matted roots that form within fractures of the soft rock. Identifying this material with bucket auger extractions is often difficult because of inevitable structure breakdown of the bedding planes (Lietzke and

Weber, 1981; Schafer et al, 1979). Errors in identification of a paralithic contact result in improper classification of soils for taxonomic and land use capability purposes.

Water Retention of Soft Bedrock

Coile (1953), measured the water retention of weathered sedimentary and igneous fragments, and the associated overlying soil in the Piedmont Plateau region. Fragments were water saturated and mixed with air-dry soil. Water was added to bring the soil to field capacity. Oat plants were used to reduce water content to wilting point. Coile found that 2 to 5 mm thick fragments contained 1 to 4 percent of plant available water, by weight.

Soil Survey Staffs from South Dakota and Montana investigated shallow soils overlying Cr horizons (Soil Survey Staff, 1978). Several soil series with Cr horizons were described and sampled without destroying the natural structure. Natural clods from each horizon were excavated and coated with saran. Clods from Cr horizons consisted of several fissile fragments with soil fines between them. Water retention was determined in pressure plate apparatus at -.010, -.033 and -1.5 MPa potential. These data are presented in Table 1. All horizons sampled contained plant available water.

Table 1: Selected water retention data from an unpublished study of paralithic material by the Soil Survey Staffs of South Dakota and Montana (Soil Survey Staff, 1978).

Depth	Horizon	Bulk Density*	Water Content (MPa) -.010	-.033	-1.5	WRD**
cm		Mg m^{-3}		%		cm/cm
13-36	C	1.21	33.8	32.1	15.0	.21
36-66	Cr	1.22	35.7	35.0	13.4	.26
0-13	A	1.22	34.4	33.8	21.8	.15
47-71	Cr1	1.23	--	38.2	25.8	.15
71-112	Cr2	1.17	46.6	44.3	28.4	.19
43-91	Cr1	1.37	23.0	19.3	4.9	.20
91-107	Cr2	1.24	38.4	32.6	16.1	.20
41-66	Cr1	1.47	29.2	21.4	6.1	.22
66-97	Cr2	1.51	27.4	23.6	5.7	.27

*Bulk density at -.033 MPa potential (field capacity); Mg m^{-3} = g/cc.

**WRD = Water retention difference.

$$WRD_{(v)} = \frac{(\theta w_{-.033MPa} - \theta w_{-1.5MPa})\ Db_{-.033MPa}}{100}$$

$WRD_{(v)}$ = Water retention difference, by volume.

$\theta w_{-.033MPa}$ = Percent moisture, by volume, at -.033MPa potential.

$\theta w_{-1.5MPa}$ = Percent moisture, by volume, at -1.5MPa potential

$Db_{-.033MPa}$ = Bulk density at -.033MPa potential.

Schafer et al, (1979), used a neutron probe to compare plant water use patterns from a shallow soil underlying soft sandstone at 50 cm and a nearby deep soil with no soft sandstone in the first 200 cm. During the summer of 1976, from June 1 to August 31, the total soil water depleted from the upper 150 cm of the shallow soil was 19.6 cm versus 22.7 cm of water depleted from the same depth of the deep soil. It appeared that much of the water depleted in the shallow soil came from soft, fragmented sandstone.

Hansen and Blevins (1979), measured water retention of sandstone and shale fragments sampled in A and B horizons. Wilting percentage was determined with a soil-fragment mixture in a greenhouse experiment, similar to Coile (1953), and with individual fragments in pressure plate apparatus. Plant available water of the fragments ranged from 4.5 to 17 percent by weight. Data from this study indicates that porous coarse fragments may provide plant available water. The authors speculated that this may be especially true under drought conditions.

METHODS

Study Area

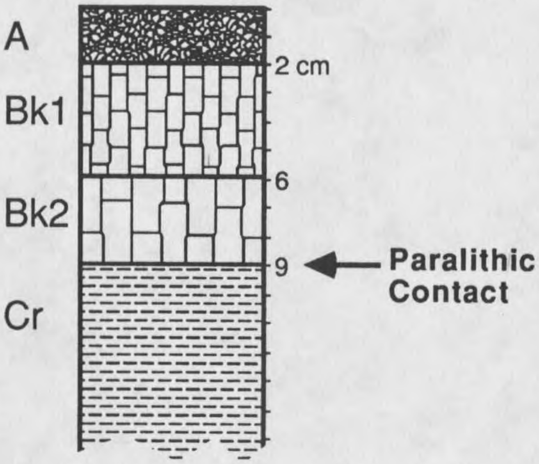
The study area is located a few miles north of Roundup, Montana in the NE 1/4 of Section 34, T10N, R25W, Musselshell County. The local soil landscape is dominated by Ustic Torriorthents formed in soft beds of sedimentary siltstone common in the Fort Union Formation. These beds were deposited during the retreat of the last major Cretaceous Sea (Veseth and Montagne, 1981). The climate is semi-arid, averaging 31 cm (12.2 inches) of precipitation, most of it coming in April, May and June (Caprio, 1984).

A Cabbart series soil pedon on a gently sloping upland sideslope was described and sampled. This loamy, mixed frigid, shallow Ustic Torriorthent has a paralithic contact at a depth of about 23 cm (Figure 1). The beds of siltstone are fissile near the contact, with plates increasing in thickness and length with depth. A detailed pedon description and auxiliary physical data are appended.

Field Sampling

Siltstone fragments from about 20 cm depth were excavated from a Cabbart soil pedon near the one described above. All fragments were approximately the same size, 4 to 5 cm in length and width, and 1.5 cm thick. The fragments were immediately coated with saran resin (Brasher et al, 1966) and stored for transport to the lab.

Figure 1: Cabbart soil profile showing soil horizons and the paralithic contact. Morphological, chemical and physical data corresponding with this figure are appended.



Bulk Density

Bulk density of each fragment was determined in the lab by water displacement. The coated fragments were weighed in the air and then submersed in water and reweighed. The weight in water is subtracted from the weight in the air to give the volume of the fragment.

Percent porosity was also calculated for each fragment as follows:

$$\left(1 - \frac{BD}{PD}\right) \text{ X } 100\% = \% \text{ porosity, where}$$

BD = bulk density of sample, and

PD = particle density, 2.65 g/cc

Sample Preparation

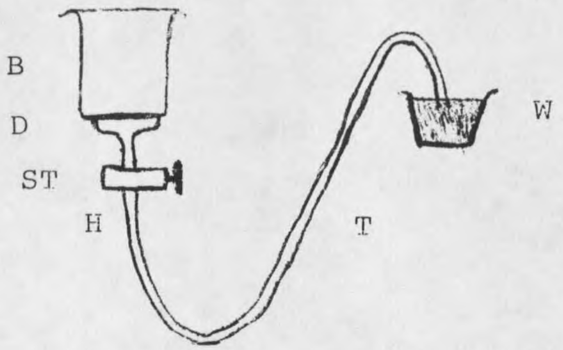
To create a smooth surface for contact between the fragment and ceramic plate a table saw with a diamond tipped blade was used to remove a patch of saran coating from the bottom of the fragment. A patch of saran was also removed from the top of the fragment to allow free flow of water.

Tension Cup

Tension cups were constructed from Buchner type filter funnels containing fritted discs (Figure 2). These funnels were modified by inserting a stop cock in the funnel neck and shrinking the end of the neck so that there was a very small outlet hole about 1 mm in diameter. Pores of the fritted discs retained water against hanging water column tensions of greater than -.01 MPa. Flexible rubber tubing was attached to the funnel neck and the free end of the tubing was placed in a water reservoir. By lowering the water reservoir, negative water potentials of up to -.01 MPa could be applied to the plate and any object on the plate. The tension cup and any material it contained could be weighed by closing the stopcock and disconnecting the rubber tubing. The small outlet hole in the neck prevents loss of water from the neck, provided the weighing is done rapidly. The water column is reconnected by reattaching the rubber tubing to the neck while water was running from the tubing.

In order to insure good hydraulic contact, a filter paper was placed between the sample and the disc. The water reservoir was then raised to the level of the disc and the system allowed to sit for 24 hours. The weight of the water in the sample at this potential of close to zero was taken as saturation. By sequentially applying more tension to the sample, sample water contents corresponding to 0, -.002, -.004, -.006, -.008, and -.010 MPa were obtained on each sample. At these high potentials, equilibrium was obtained in approximately one hour.

Figure 2: Tension cup assembly for water retention measurement between 0 and -.010 MPa potential. B = Buchner type funnel; D = fritted disc; ST = stop cock; H = small outlet hole; T = rubber tubing; W = water reservoir (water table).



Pressure Plate Extractor

Water contents corresponding to −.03, −.1 and −1.5 MPa potential were obtained on these same samples with a pressure plate apparatus. A 2-bar plate was used for the two higher potentials and a 15-bar plate was used for the lower potential. In order to insure hydraulic contact between the samples and the porous plates, a thin layer of kaolonite (a non-swelling clay) was placed between the plate and the sample. The sample was saturated on the plate for 24 hours and the desired pressure was applied to the chamber; this required 6-8 days at −.033 MPa, 7-9 days at −.1 MPa, and 9-12 days at −1.5 MPa. After equilibrium was reached, the sample was removed from the chamber, the kaolonite carefully removed, and the sample weighed. It was then used at the next lower potential. After obtaining these data, the oven dry weight of the sample was obtained.

Moisture content was calculated as follows:

$$\frac{W1-W2}{W2} \times 100 \times Db = \theta_w; \text{ where}$$

W1 = Weight of fragment and water;

W2 = Oven-dry weight of fragment;

Db = Air Dried bulk density of fragment; and

θ_w = Percent moisture, by volume.

A potential problem with this method is the repeated drying and resaturation of the same sample. The expansion and contraction of pore spaces may cause some breakdown of structure. Some fragments had to be discarded before all extractions were completed. Results are only for those samples without apparent structure deterioration.

RESULTS AND DISCUSSION

Table 2 lists bulk density, calculated porosity and measured water retention at saturation for twenty siltstone fragments. The average bulk density of the 20 siltstone fragments was 1.97 g/cc. This is comparable to Hanson and Blevins (1979), who measured water retention of shale fragments with an average bulk density of 2.07 g/cc. Both studies calculated the bulk density for individual, air-dried fragments. The Soil Survey Staff (1978), and Schafer et al, (1979), reported bulk density of Cr horizons ranging from 1.48 to 1.82 g/cc. These latter studies sampled fissile sedimentary fragments of varying textures with soil fines between the individual fragments. This may explain the lower densities.

Calculated percent porosity was higher than percent water by volume at saturation for all but two fragments. Percent porosity indicates total pore space. It includes discontinuous pore spaces that might not be filled with water even under saturated conditions. Higher percent saturation of fragments 14 and 15 may be a result of pore wall breakdown due to the expansion and contraction from repeated wetting and drying.

Table 2: Bulk density, calculated porosity and water retention at saturation for 20 siltstone fragments.

Sample number	Bulk density (air dry)	Calculated porosity	Water retention at saturation (volume basis)
	g/cc	%	%
1	2.01	24.15	24.52
2	1.95	26.41	24.57
3	1.97	25.66	25.02
4	1.89	28.68	25.70
5	1.96	26.04	25.48
6	2.02	23.77	23.63
7	1.88	29.06	24.82
8	2.00	24.53	23.00
9	1.97	25.66	25.22
10	1.97	25.66	25.41
11	1.95	26.42	24.57
12	1.89	28.68	25.89
13	1.91	27.92	25.59
14	2.03	23.40	24.36
15	2.11	20.38	21.52
16	1.96	26.04	25.28
17	1.99	24.91	23.08
18	1.96	26.04	25.09
19	2.05	22.64	22.55
20	1.98	25.28	22.97
$\overline{X}$	1.97	25.57	24.41

$\overline{X}$ = mean

Table 3 shows percent by volume of water retained at the measured potentials between 0 and -1.5 MPa. In theory, water held at potentials of less than -.01 MPa would be expected to drain fairly rapidly from the system provided there is downward pore continuity, and thus, in a few days after becoming wet to 0 MPa, would be lost from the root zone. Also, in theory, water held between about -.01 and -1.5 MPa would be retained in the profile and be available for plant use. However, this is highly dependent on the proximity of roots. It is unlikely, considering the average bulk density of nearly 2.0 gm/cm^3 that roots can penetrate the rock fragments. Thus, water held in the fragments must move to the roots. Water held at potentials between about -.01 and -.1 MPa probably moves reasonably rapidly to the roots by unsaturated flow. On the average, this would mean that about 5 percent by volume of the water held in rock fragments is readily available to roots. Water held between -.1 and -1.5 MPa would move much slower because the water films at these potentials are so thin that flow is retarded. This water could be considered available to the plants, provided the plants had other water to help sustain them while the slow movement occurred. On the average, water retained between -.1 and -1.5 MPa could provide another 5 percent, by volume, of water to the plants from the rock fragments.

Table 3: Water retention data for 20 siltstone fragments for the 0 to -1.5 MPa potential range. Water content is reported as percent water by volume.

	Tension Cup Ψ = MPa						Pressure Plate Ψ = MPa		
Sample	0	.002	.004	.006	.008	.010	.033	.1	1.5
1	24.52	23.72	23.52	23.12	23.12	22.51	16.68	14.47	9.85
2	24.57	25.16	23.01	22.62	22.23	21.84	16.97	15.60	10.53
3	25.02	24.23	24.03	23.23	22.85	22.66	19.31	18.32	12.21
4	25.70	25.70	25.14	24.95	24.57	24.38	19.66	17.96	14.55
5	25.48	25.09	24.89	24.11	23.91	23.72	15.29	13.52	9.80
6	23.63	22.62	22.42	21.92	21.61	21.21	18.38	17.17	10.10
7	24.82	24.06	23.12	22.56	22.18	21.81	15.80	13.54	9.21
8	23.00	23.00	22.60	22.20	22.00	21.60	18.20	17.20	14.00
9	25.22	24.03	23.64	23.05	22.66	22.46	18.52	17.14	13.20
10	25.41	23.44	21.47	20.30	19.50	18.32	18.72	17.93	13.59
11	24.57	21.65	21.06	20.09	19.89	19.31	17.94	17.36	11.70
12	25.89	24.76	24.19	23.44	23.25	22.49	19.47	15.88	11.15
13	25.59	25.02	24.26	24.07	23.88	23.30	20.06	19.48	11.27
14	24.36	24.36	21.92	20.91	20.71	20.30	17.26	14.21	9.54
15	21.52	21.31	21.31	19.83	19.83	19.62	17.94	14.56	10.97
16	25.28	24.30	22.93	22.54	21.76	21.95	17.64	14.31	10.00
17	23.08	22.49	22.29	22.29	22.29	21.89	17.71	13.53	8.96
18	25.09	25.09	24.50	22.15	21.76	21.56	21.56	17.44	12.94
19	22.55	22.14	21.94	21.73	21.53	18.04	16.81	15.58	12.10
20	22.97	22.57	20.79	20.59	20.32	18.61	15.84	15.25	9.90
$\overline{X}$	24.41	23.74	22.95	22.28	22.00	21.38	17.99	16.02	11.28
σ	1.217	1.277	1.303	1.405	1.416	1.796	1.562	1.818	1.688

$\overline{X}$ = mean value

σ = standard deviation

These data bring out the importance of the size of the rock fragments in terms of their contribution of water to the plants. Since water movement would be slow, especially at potentials much in excess of about -.1 MPa, water retained in the interior of large fragments might not be delivered to the plant roots rapidly enough to sustain the plants. Conversely, most of the water retained in relatively small fragments would probably be delivered relatively rapidly to roots on the edges of the fragments.

Table 4 identifies the water retention difference using .010 and .033 MPa as field capacity. Results are reported as percent moisture by volume and cm of plant available water per cm of fragment. An average of .10 and .07 cm of water per cm of siltstone fragment is available to plants, using .010 and .033 MPa tension respectively as field capacity.

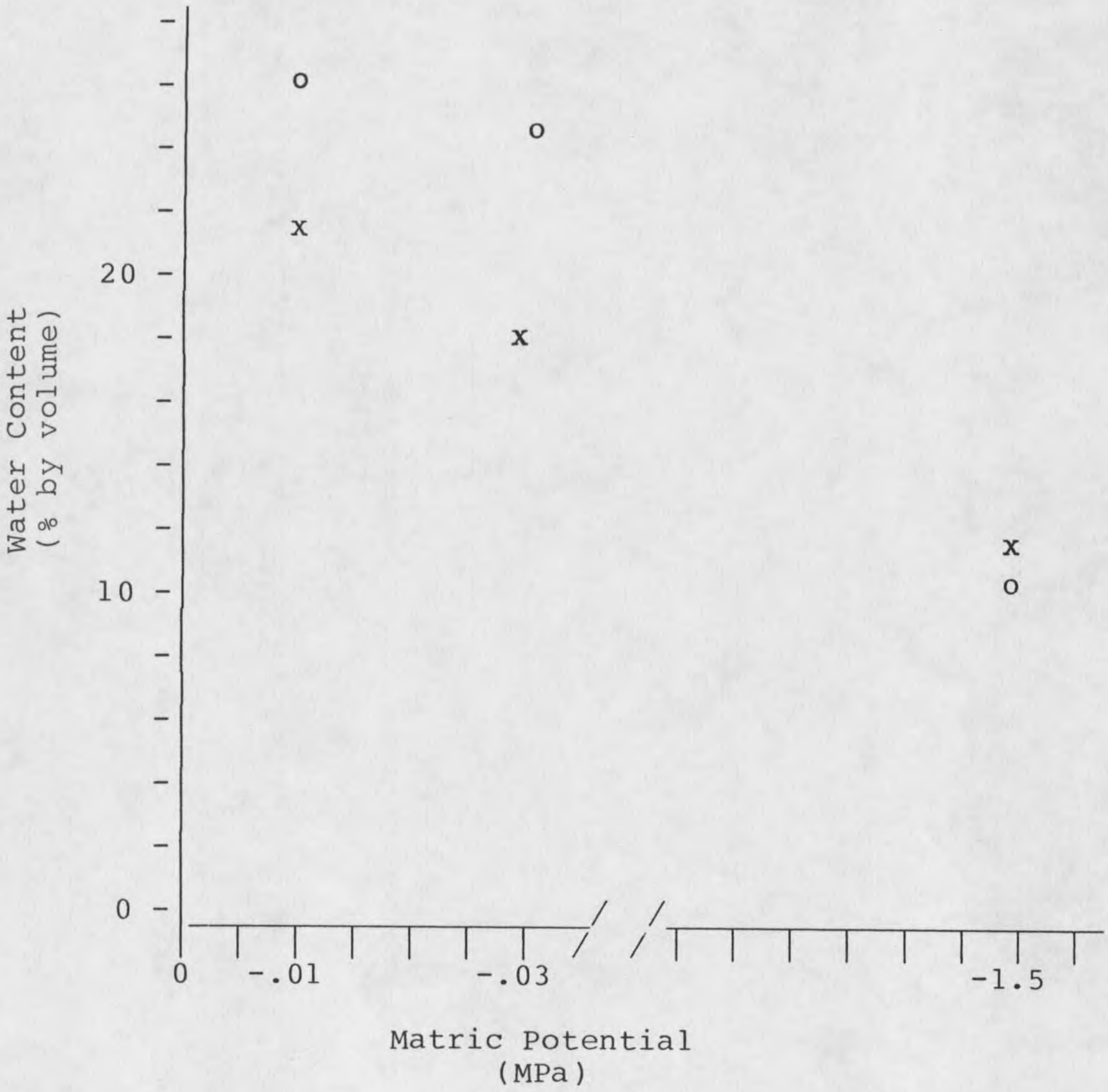
Figure 3 compares the water retention of the 20 siltstone fragments and the loamy A horizon of the Cabbart pedon described near the excavation for the sample fragments. The siltstone fragments hold less water than the loamy soil material at low tensions because the siltstone has fewer large pore spaces. At high tensions these fragments may hold slightly more water then the A horizon because they have more small pores.

Table 4: Water retention difference (WRD) for 20 siltstone fragments.

	FC = -.010 MPa		FC = -.030 MPa	
Sample number	WRD	water/ siltstone	WRD	water/ siltstone
	%	cm/cm	%	cm/cm
1	12.66	.12	6.83	.07
2	11.31	.11	6.44	.06
3	10.45	.10	7.10	.07
4	9.83	.10	5.11	.05
5	13.92	.14	5.49	.05
6	11.11	.11	8.28	.08
7	12.60	.13	6.59	.07
8	7.60	.08	4.20	.04
9	9.26	.09	5.32	.05
10	4.73	.05	5.13	.05
11	7.61	.08	6.24	.06
12	11.34	.11	8.32	.08
13	12.03	.12	8.79	.09
14	10.76	.11	7.72	.08
15	8.65	.09	6.97	.07
16	11.95	.12	7.64	.08
17	12.93	.13	8.75	.09
18	8.62	.09	8.62	.09
19	5.94	.06	4.71	.05
20	8.71	.09	5.94	.06
$\overline{X}$	10.10	.10	6.71	.07

$\overline{X}$ = mean

Figure 3: Water retention for the mean of 20 siltstone fragments (x) and the loamy A horizon of a Cabbart pedon (o).



CONCLUSIONS

The data indicate that plant available water is held in soft siltstone fragments. The mean amount of water retention for the 20 fragments tested was 0.10 cm of plant available water per cm of siltstone when field capacity was defined as -0.010 MPa potential and .07 cm when field capacity was defined as -.033 MPa potential.

Coile (1953), Soil Survey Staff (1978), Schafer et al, (1979), and Hanson and Blevins (1979), all reported data similar to those collected in this study, indicating that various types of soft rock can hold plant available water. These studies show that water held in soft rocks can be absorbed by plant roots at potentials between about -.01 and -.1 MPa.

The matting of roots commonly observed along the fractures of the soft sedimentary bedrock indicate that roots do exploit fragments similar to those tested. Soft rock fragments appear to act much like other soil material, except roots cannot penetrate them.

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APPENDICES

APPENDIX A

Cabbart Pedon Description

Cabbart soils develop on stable sedimentary plains in southeastern Montana. This description is similar to the typical Cabbart.

Classification: Loamy, mixed, frigid, shallow Ustic Torriorthent.

Pedon: Cabbart loam.

Location: Musselshell County, Montana; a few miles north of Roundup.

Physiographic position: Gently sloping upland sideslope.

Drainage: Moderately well drained.

Vegetation: Grassland with Koleria cristata, Bouteloua gracilis, and Carex filifolia as fragments.

Remarks: Matted roots are commonly observed along the fractures of the soft beds of siltstone.

Colors are for dry soil.

A 0-5 cm (0-2 in.). Light olive brown 2.5Y 5/4 loam; weak fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine roots and pores; clear wavy boundary.

Bk1 5-15 cm (2-6 in.). Light yellowish brown 2.5Y 6/4 loam; weak medium prismatic structure; hard, friable, slightly sticky and slightly plastic; common fine roots and pores; clear wavy boundary.

Bk2 15-23 cm (6-9 in.). Pale yellow 2.5Y 7/4 silt loam; weak medium to coarse prismatic breaking to moderate medium platy structure; hard, friable, slightly sticky and slightly plastic; common to few fine to medium roots; clear wavy structure.

Cr 23-61+ cm (9-24+ in.). Light yellowish brown 2.5Y 6/4 silt loam; strong thin platy structure; hard, friable, slightly sticky and slightly plastic; common fine to medium roots between platy siltstone fragments.*

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* The fragments and soil fines between the fragments have a similar color. The moist consistency is firmer than that of the associated soil fines.

APPENDIX B

Table 5: Lab Characterization for the Cabbart Pedon

		Particle Size			Water Content			
					-.010	-.033	-1.5	
Horizon	Depth	Sand	Silt	Clay	MPa	MPa	MPa	Db
	cm	%						Mg m^{-3}
A	0-5	40	46	14	25.99	24.74	10.29	1.39
Bk	5-23	35	48	17	-	-	-	1.45
Cr	23-61+	14	68	18	-	-	-	1.67

Horizon	pH (1:1 H_2O)	EC	Exchangeable Cations Ca	Mg	K	Na
		mmhos	me/100 g			
A	7.9	.49	27.36	1.99	.605	.078
Bk	8.3	1.14	31.36	2.19	.277	.313
Cr	8.2	7.48	30.51	6.96	.220	3.38

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