Application of Soil HoH

Brian Tunstall

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Abstract

Results are presented to demonstrate the application of the Soil Heat of Hydration (Soil HoH) measurement in addressing land use and management. The results demonstrate the differences between soils and the effects of soil salinity. Changes in Soil HoH associated with land use impacts are given.

Introduction

Soil HoH is a calorimetric measurement of the increase in temperature that occurs when water is added to dry soils. Soil HoH represents the release of energy with the dissociation of hydrogen bonds when water adsorbs to the surface of materials such as clays and organic matter.

The results here demonstrate application of the Soil HoH measurement to soil characterisation and land management issues. Observations were obtained to demonstrate the utility of the measurement and to examine the effects of clay, organic matter and salinity on the Soil HoH measurement. The main factors investigated were different soils, the salinity of soils, and land use impacts.

Background

Soil property measurements provide essential information when addressing land use and management. Agricultural management depends on information on the structural and chemical properties of soils and such properties are of consequence for engineering applications.

The soil properties of most consequence for agriculture relate to the adsorption, retention and release of water and nutrients. Clays have high water storage capacities but low permeability while sands are the reverse. However, different clay minerals vary greatly in their ability to store water and nutrients and these differences are generally associated with differences in the levels of aggregation and hence structural stability.

Determination of the mineral composition of clays in soils is expensive. Moreover, knowledge of the composition does not necessarily clearly define consequences of the mineral composition for a particular application particularly since levels of soil organic matter can affect the water holding characteristics of soils more than clays.

An ability to directly determine the effects of clay and organic matter on the soil performance would be beneficial in addressing land management. Direct measurement of the capacity of a soil to bind water and nutrients would have direct application in assessing the agricultural quality of soils and in monitoring changes associated with land management practices.

The cation exchange capacity (CEC) measurement quantifies the adsorption of an introduced cation and so provides a good indication of the ability of a soil to retain nutrients. The multi-step process for measuring CEC is reasonably time consuming and, while the measurement is directly applicable to nutrient retention, the results do not provide direct information on the water retention or structural characteristics of the soil.

The desired soil property measurement would relate to the active surface area of clay and other fine materials in the soil as this determines its ability to adsorb water and ions. It therefore determines the ability of the soil to retain nutrients. It would likely also determine other characteristics, such as the water release characteristics of the soil, its swell-shrink properties, and the response to mechanical impact. The Soil HoH measurement addresses this requirement in directly reflecting the ability of the soil surfaces to bind water.

Methods

Different Soils

The soils used to develop the method and examine effects of added salt salinity are described in Table 1. Most measurements were conducted on samples of the A1 and B2 horizon of the red clay and grey clay, and humus. These provided two different clays with and without organic matter, and pure organic matter.

Table 1. Characteristics of the main soils analysed.

RA	Red Clay A1	Medium heavy-clay, appreciable organic matter.
RA2	Red Clay A2	Medium-heavy clay, low organic matter
RB	Red Clay B2	Heavy clay, effectively zero organic mater.
GA	Grey Clay A1	Medium heavy clay, appreciable organic matter
GB	Grey Clay B2	Medium heavy clay, no organic matter or structure
Hu	Humus	Humic soil layer developed from acacias
Sa	Sand	Washed river sand

Soil HoH measurements were also obtained for a range of soil samples obtained during the conduct of soil surveys in NSW. Measurements previously obtained for these samples were field texture, pH, oxidation reduction potential and electrical conductivity on 1:5 soil:water samples and a dispersibility ranking. The oxidation reduction potential is presented as a concentration (pe) to allow direct comparison with pH.

Samples were also obtained from heavy cracking clay soils in northern NSW and southern Queensland to identify the likely range of HoH associated with clay. The sites contained native vegetation with limited impact of land use.

Soil Salinity

The salinity of soils was increased by adding known quantities of saline water of known concentrations and then drying the soil. The percent added salt, on a gravimetric basis, is given in Table 2. The salinised samples were sun dried over several days. Most comparisons are based on measurements on the sun dried soils. Duplicate measures were obtained for each treatment.

The effect of natural soil salinity on Soil HoH was assessed by leaching salt from a naturally hyper-saline clay.

Table 2. Amounts of salt added to increase soil salinity (% gravimetric).

	Added Salt	0	1	2	3
GA, GB		0	1.2	2.3	3.5
RA, RB		0	1.4	2.8	4.2
Hu		0	2.8	5.6	8.4

Impacts of Land Use

These observations demonstrate the applicability of the Soil HoH measurement in evaluating and monitoring land use impacts on soils. Two forms of comparison were made:

a. Between sites where the reference as well as the 'impacted' site had generally been subject to a land use impact (Group a).
b. Between intact, ungrazed native vegetation and farmland (Group b).

Table 3. Characteristics of Group (a) sample sites used to examine the effects of land use on soil HoH.

		Intact Condition	Impacted Condition
M	Murrumbateman	Cleared, dense ungrazed Phalaris	Cleared, heavily grazed 'native' grasses
Y	Yass	Cleared, dense Phalaris, sparse eucalypts	Grazed (cattle) Phalaris, sparse eucalypts
G	Gooda Creek	Open eucalypts, native grasses	Open eucalypts, grazed native grasses
H	Hall	Open woodland, Themeda triandra	Cleared, essentially ungrazed Themeda triandra
NP	Nature Park	Intact eucalypt woodland	Cleared and slashed, ungrazed native grasses
R	Racecourse	Dense Phalaris, exotic trees	Grazed 'native' grassland

Group (a)

Paired observations were obtained at the reference and impacted sites generally less than 10m apart but separated by a fence. The site characteristics are given in Table 3. All reference sites had a dense cover of standing organic matter covering the soil, both dead and live material. All ‘impacted’ sites, except the cleared Themeda (H), had substantial amounts of exposed, bare soil generally through being grazed by livestock.

Group (b)

These observations are similar to Group (a) but were designed to examine the nature of changes in the surface soil relative to the subsoil, and to characterise soils under intact, ungrazed native vegetation. Paired samples were obtained in ‘intact’ and ‘impacted’ sites separated by a fence as for Group (a). The characteristics of the sampling for Group (b) are:

a. Single borehole at each site.
b. Samples obtained for the A1, A2 and B2 soil horizons.
c. Reference site comprising uncleared native vegetation ungrazed by domestic livestock.

Sample sites in farmed areas located beyond the influence of trees in the adjacent intact site (> twice the height of the trees from the fence).

Most sites were located along a railway line to obtain ungrazed native vegetation. The characteristics of the sites are given in Table 4. Limitations of the sites are:

a. The reference site for Acacia had been subject to clearing around 15 years prior to sampling.
b. The Poplar Box site was heavily grazed by rabbits.
c. The Yellow Box site was adjacent to a drainage line and there were differences between soil samples unrelated to land use.

The reference (intact) sample for the Nature Park site in Table 3 is equivalent to the intact sites in Table 4 in being uncleared, ungrazed native vegetation.

Table 4. Characteristics of sample Group (b) sites used to examine the effects of land use on soil HoH.

Site	Intact Condition	Impact
Yellow Box	Open Yellow box woodland along a drainage line, grassy understorey. Deep litter layer.	Clearing Grazing
Ironbark	Mid dense ironbark woodland, some poplar box. Shrub understorey with dianellas. Deep litter layer.	Clearing Cropping
Mallee	Mid dense Mallee with ironbarks. Dianellas dominant in understorey. Deep litter layer.	Clearing Cropping
Acacia	Dense regrowth Acacia pendula (approximately 15 years old). No understorey vegetation. Light litter layer.	Clearing Cropping
Poplar Box	Mid dense Poplar Box with limited Callitris. Sparse shrub understorey vegetation. Deep litter layer.	Clearing Cropping

HoH calculations

The measurement procedures and calculations were as described in the paper on the method. A specific heat of 1.1 was assumed for all samples except for Group b. The specific heats other than 1.1 used for Group b soils were 1.4 for all A1 horizons with very high organic levels and 1 for all A2 and B horizons.

Table 5. Soil properties for the A2 and B2 horizons for samples obtained in association with a number of soil surveys.

S*	#		HoH	Texture	EC	pH	pe	pe/pH	D*	Geology
			J/g	Descriptor	µs/cm					
LT	a	A2	1.9	Fine Sandy-loam	9	6.5	7.2	1.1		Granite
		B2	5.7	Clay Sandy-loam	36	6.3	7.3	1.2	5	
	b	A2	1.3	Clayey Sand	6	5.9	6.7	1.1		Granite
		B2	4.6	Sandy-clay	20	5.9	6.7	1.1	6	
	c	A2	1.0	Clay Sandy-loam	4	6.4	7.2	1.1		Granite
		B2	4.4	Fine Loam	24	5.6	7.7	1.4	1	
	d	A2	1.3	Clay Sandy-loam	9	6.1	7.4	1.2		Granite
		B2	3.6	Sandy Clay-loam	9	5.9	7.5	1.3	5	
	e	A2	2.0	Clay Sandy-loam	5	5.7	7.4	1.3		Sedimentary
		B2	13.3	Sandy Clay-loam	5	6.1	7.3	1.2	3	
RH	f	A2	8.5	Sandy-loam	7	6.8	7.2	1.1		Shale
		B2	6.6	Loam	10	6.4	7.1	1.1		
	g	A2	8.6	Clay Sandy-loam	7	6.1	6.8	1.1		Shale
		B2	17.9	Fine Sandy-loam	10	5.9	6.9	1.2		
	h	A2	9.3	Loam	21	6.0	7.3	1.2		Shale
		B2	13.4	Fine Sandy-loam	48	5.8	7.3	1.3		
CJ	i	A2	3.5	Sandy Clay-loam	4	6.9	6.3	0.9	3	Colluvium
		B2	7.8	Sandy-clay	5	7.5	6.0	0.8	3	
	j	A2	2.2	Sandy Clay-loam	4	6.7	6.4	1.0	3	Colluvium
		B2	11.7	Sandy-clay	22	7.1	6.6	0.9	5	
	k	A2	5.9	Silty-clay	10	7.3	7.2	1.0	3	Colluvium
		B2	8.9	Light-clay	10	7.4	7.0	0.9	3	
	l	A2	5.0	Clayey Sand	6	7.5	7.2	1.0	5	Colluvium
		B2	15.6	Sandy-clay	4	7.3	7.5	1.0	3	
	m	A2	7.3	Clay-loam	4	6.4	7.6	1.2	5	Alluvium
		B2	13.3	Light-clay	5	6.9	6.5	0.9	3	
PR	n	A2	5.5	Sandy Clay-loam	64	8.4	7.3	0.9		Volcanic
		B2	8.6	Very Heavy-clay	331	8.6	7.3	0.8	3	
	o	A2	4.9	Sandy Clay-loam	43	7.1	7.3	1.0		Volcanic
		B2	7.4	Medium-clay	25	7.3	7.2	1.0	5	
	p	A2	7.1	Sandy-clay	30	6.2	7.7	1.2		Volcanic
		B2	7.8	Sandy-clay	17	7.2	7.4	1.0	5	
	q	A2	2.9	Sandy Clay-loam	17	6.1	7.4	1.2		Sedimentary
		B2	16.7	Heavy Medium-clay	34	7.9	7.2	0.9	5	

S* Survey code

D* Dispersibility ranking (1 = non slake or dispersive, 6 = fully dispersive)

Results

Soil Type

The HoH for a range of soils on different geologies is given in Table 5 along with the general geology and other soil property measurements. The HoH ranges from 1 to 9.3J/g for the A2 horizons and 3.6 to 17.9 for the B2. The A2 HoH is always lower than the B2 except for one sample.

Sites a - d from the Braidwood granites have similar and low HoH values. The Braidwood Granites are recognised as being ‘poor’ soils susceptible to drought and structural decline through mechanical disturbance. The Soil HoH on the adjacent sedimentary formation is higher for the B2 horizon than the granite hence the origin of the parent material for the soils is differentiated by the HoH.

The HoH for soils derived from shale (f, g, h) exhibit a high HoH relative to their texture. The B2 horizons for sites g and h, each with clay Sandy-loam textures, have HoH values of 17.9 and 13.4 respectively. Site f is unusual with the HoH being higher for the A2 than for the B2 horizon.

Soils derived from the colluvial/alluvial material exhibit the ‘usual’ pattern of the HoH for the B2 horizon being around double that of the A2. There is no direct relationship between HoH and texture with subsoils for sites i, j and l, each with sandy-clay textures, having HoH values of 7.8, 11.7 and 15.6 respectively. As the other properties are similar for these soils the HoH is providing additional information.

Soils on the volcanic formation have a lower difference in HoH between the A and B horizons than most other soils. The soil on the sedimentary formation in this survey (q) shows a marked difference between the HoH for the A2 and B2 horizons, as with other similarly derived soils (e, m).

Table 6. HoH measurements for heavy clay soils.

Community	HoH (J/g)	Texture
Acacia harpophylla		
A1	26.4	Heavy clay
A2	25.2	Heavy clay
B2	25.0	Heavy clay
Acacia pendula		
A1	23.7	Heavy clay
A2	23.3	Heavy clay
B2	30.2	Very Heavy clay
Casuarina cristata		
A1	22.9	Clay loam
A2	12.5	Silty clay
B2	24.8	Heavy clay

The highest HoH recorded for mineral soil was for the subsoil associated with *Acacia pendula* on a black cracking clay soil near Moree (Table 6). The HoH of the cracking clays is high throughout the profile and, like the gilgaied grey cracking clay associated with *Acacia harpophylla* shows little difference in texture or HoH between the A1 and A2 horizons. In contrast the soil associated with *Casuarina cristata* shows a much higher HoH for the A1 than the B2 horizon associated with accumulation of organic matter.

Soil Salinity

Results for soils salinised to different levels are given in Table 7. The relativities between soils are the same across all salinities with humus having by far the highest HoH. The organic GA soil has the highest HoH of the mineral soils and the GB soil the lowest. The differences in HoH within soil profiles are less than between the soil types.

Soil salinity significantly decreases the HoH for all except a few comparisons. The exceptions likely arise because of the appreciably higher moisture content for the GB-0 and Hu-1 samples (Table 8). Table 9 gives the magnitude of differences in HoH between adjacent salinity levels (0-1, 1-2 and 2-3). Humus exhibits a significantly higher change than the other soils. The proportional decrease in HoH tends to decrease with increase in salt content but this result is not significant at the P=0.05 level.

Table 7. HoH (J/g) determinations for different soils subject to different levels of salinisation. SE 0.309

Soil	Added Salt			
	0	1	2	3
GA	13.7	12.1	9.2	8.9
GB	3.9	2.5	1.6	0.7
RA	9.4	9.5	7.1	6.4
RB	7.9	6.5	5.2	4.3
HU	65.6	50.6	52.3	46.4

Table 8. Water content (%) of air dried samples used to produce the results in Table 7.

	0	1	2	3
GA	0.49	0.60	0.96	0.70
GB	0.37	0.14	0.12	0.24
RA	0.60	0.59	0.68	0.93
RB	0.42	0.63	0.34	0.20
Hu	2.21	3.09	2.39	2.74

Table 9. Mean differences in changes in Soil HoH (J/g) between soils and salt contents.

Soil	Mean	Salinity	Mean
GA	1.171	1.000	2.231
GB	0.711	2.000	1.504
RA	0.552	3.000	0.754
RB	0.890		
Hu	4.158		
SE	0.225	SE	0.174

It is likely that the magnitude of the decrease in HoH proportionally decreases with increasing salinity but this is masked by the variability between samples. This variability arises, at least in part, from differences in the moisture content of samples.

The HoH for the sun dried saline clay was appreciable at 7.7 J/g and this increased to 15.9 J/g with oven drying at 105°C (Table 10). The HoH increased further following leaching of salt. The highest HoH (26.3J/g) was achieved with maximum leaching but the gain in HoH declined as the level of leaching increased. The adsorption of NaCl reduces the ability of clay and organic matter to bind water and the effect is reversible.

Table10. HoH (J/g) determinations for saline clay subject to different levels of leaching of salt by water.

Leaching Ratio	EC mS/cm	% salt	HoH (replicates)	HoH (mean)
0 (air)	9.39	4.7	8.9, 6.9, 7.3	7.7
0 (oven)	9.39	4.7	15.9, 16.5, 15.2	15.9
1:5		1.19	24.1, 24.7	24.3
1:5		1.19	23.5, 24.0	23.8
1:50	0.76	0.15	26.4, 26.2	26.3

Table 11. Mean HoH (J/g) for soil samples obtained from Group (a) paired sites subject to different land uses. Site codes given in Table 4.

Site	Reference	'Impacted'	Difference	Significant Difference
Y	8.37	16.02	+7.65	✓
R	12.72	12.20	-0.52	×
NR	13.85	9.15	-4.70	✓
Go	5.53	5.65	+0.12	×
Ha	13.37	9.92	-3.45	✓
Mu	5.97	6.07	+0.10	×

Land Use Effects

Group a

Soils from the different sites generally differed in their HoH. Also, for three of the six sites there were significant differences between the reference and 'impacted' states (Table 11). The HoH for the impacted Yass site was 7.65 J/g higher than for the reference site, a 91% increase. The impacted samples were obtained from the outer perimeter of a cattle camp and so had enhanced accessions of organic matter.

The land use impacts reduced the HoH by around 4 J/g for other sites that showed significant land use effects. The percentage decrease was 34% for the nature reserve and 26% for Hall. The impact at the nature reserve was denudation of the ground cover by regular but infrequent mowing. The impact at Hall was prior clearing of the overstory vegetation. The Hall paddock was previously grazed but livestock had been excluded for a considerable period.

The Gooda Creek (Go) and Murrumbatemun (Mu) soils were similar and derived from the same volcanic material. The absolute HoH values were the same for both soils and neither showed a significant effect of land use.

Table 12. Soil HoH, pH and EC of A1, A2 and B2 horizons for intact reference sites and farmed country for different native vegetation types (Group b). Community descriptions are given in Table 4.

	Horizon	HoH	Texture	pH	EC
		J/g			µS/cm
Yellow Box	SE	0.179			
Intact	A1	32.9	Clay-loam	6.5	90
	A2	10.8	Sandy-clay	6.2	10
	B2	11.6	Heavy Medium-clay	6.6	30
Farmed	A2	10.0	Clay-loam	6.4	20
	A1	13.0	Silty Clay-loam	6.8	10
	B2	13.3	Heavy Medium-clay	6.5	60
Ironbark	SE	0.116			
Intact	A1	22.8	Silty Loam	5.4	130
	A2	10.9	Silty Clay-loam	5.0	40
	B2	6.7	Light-clay	4.7	90
Farmed	A2	10.5	Clay Loam	5.6	70
	A1	8.5	Light-clay	4.8	90
	B2	4.4	Light-clay	5.2	20
Mallee	SE	0.220			
Intact	A1	40.9		7.1	210
	A2	10.8	Silty Clay-loam	7.2	40
	B2	11.6	Light-clay	7.1	60
Farmed	A2	10.0	Silty Loam	7.4	20
	A1	13.0	Silty Clay-loam	7.2	30
	B2	13.3	Light-clay	7.4	10
Acacia	SE	0.280			
Intact	A1	15.5	Silty-clay	4.6	90
	A2	13.7	Silty-clay	5.4	50
	B2	26.0	Heavy Medium-clay	8.4	80
Farmed	A2	14.0	Silty-clay	5.5	140
	A1	13.7	Silty-clay	5.5	70
	B2	27.0	Heavy Medium-clay	6.3	50
Poplar Box	SE	0.242			
Intact	A1	33.1	Silty Loam	6.9	440
	A2	10.0	Silty-clay	6.7	130
	B2	20.2	Medium-clay	6.7	40
Farmed	A2	8.8	Silty-clay	6.8	80
	A1	12.1	Light-clay	6.6	30
	B2	17.4	Medium Light-clay	6.8	30

Group (b)

Differences associated with site, horizon and impact were all significant (Table 12). The results are presented for each situation as the profile / treatment interactions were also significant.

The main feature of the results is the very high HoH for the A1 horizon in reference (intact) sites associated with the accumulation of organic matter. The farmed sites had much lower levels of surface soil organic matter than the reference sites. The accumulation of organic matter in the surface soil is reflected in a higher electrical conductivity.

The Acacia site shows least difference between the HoH for the A1 horizons in 'intact' and farmed sites. This reference (intact) site had been previously cleared and had a limited litter layer compared with the other reference sites. The limited litter layer may be due to the nature of the vegetation as well as prior clearing.

The Soil HoH for the A2 and B2 horizons was similar between farmed and reference sites but the small differences were generally statistically significant. Some of these differences would be real as two of the soils were more leached in farmed areas than in the reference sites. Moreover, most of the farmed soils were shallower than the reference sites due to pronounced surface soil compaction. However, the statistical tests in Table 10 are based on replicate measures rather than replicate samples and further sampling would be needed to determine if these differences are significant.

The differences between the Soil HoH for the different communities were generally as expected with the Acacia occurring on the heaviest clay and the Mallee on the sandiest soil. The HoH of the Acacia subsoil was very high at 27J/g.

Other differences observed between soil properties for different plant communities are also important but these are correlated to some extent with texture, such as profile depth. The intact Acacia soil was shallow while that for Poplar Box was comparatively deep.

The soil pH was generally consistent within sites. The exception, one value for the Acacia site, is likely associated with localised carbonate accretion.

Conclusions

The Soil HoH measurement shows large differences between soils, between different land uses on the same soils, and between the same soils subject to different levels of salinity. The HoH measurement can therefore be used to evaluate the suitability of soils for different purposes and for evaluating and monitoring the impacts of land use and management.

The Soil HoH measurement can be used to evaluate the impacts of land use on organic matter provided differences associated with the level and type of clay are taken into account. Opportunities exist for separating the effects of organic matter and the type and level of clay in field survey given assumptions as to the nature of profile development. The A1 represents a zone of accumulation of organic matter, the A2 as a zone of leaching, and the B2 the accumulation of clay. Comparison of the SoilHoH for the A1 and A2 can therefore identify the level of accumulation of organic matter in the A1 assuming minimal accumulation in the A2 and equivalent mineral compositions for the A1 and A2. The measurement on the B2 identifies the level of reactivity of the clay and therefore aids in interpreting texture measurements.

Site Selection / Evaluation

Site selection involves evaluating the suitability of sites for particular purposes, such as engineering construction and agriculture. The soil properties are usually prime determinants of site suitability and can exclude some land uses or necessitate particular management practices.

The desirability of particular soil characteristics varies depending on the application. Highly reactive clays are generally productive for agriculture but pose engineering constraints due their swell-shrink properties. Reactive soils store considerable water, retain nutrients, and are stable under tillage, and this makes then generally suitable for agriculture. Stable soils are desirable from an engineering perspective.

The engineering implications of the HoH measurement have yet to be evaluated. However, as water adsorption is linked with the swelling of clays, the HoH potentially provides a reliable measure of their stability. In conjunction with knowledge of texture it may also be a good indicator of the susceptibility of soil to structural decline in agriculture through mechanical disturbance such as tillage.

Application of soil HoH will be most beneficial when conducted in association with other soil property measurements. For example, while a high HoH for subsoils identifies the occurrence of reactive clay this association need not arise for surface soils due to the effects of organic matter. The HoH is most readily interpreted and applied when obtained in association with independent measurements of soil texture.

Performance Monitoring

The Soil HoH provides a simple, sensitive, and reliable means of monitoring losses and improvements in soil organic matter. It quantifies the effects of a loss of organic matter associated with agriculture and can therefore be used to monitor improvements.

The HoH measurement can also be used to quantify the significance of structural decline in clays due to NaCl. Indeed, the HoH measurement indicates that the NaCl decreases the effective water holding capacity of soils in addition to the known effects in decreasing permeability. Combined monitoring of Electrical Conductivity and the HoH would allow evaluation of the significance of salt accumulations to soil structure.