# Representative Soil Water Benchmarking Site Selection

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## Abstract

Soil moisture is a key hydrological factor affecting soil productivity as well as greenhouse gas emissions. There is strong spatial variability in field soil water, which requires monitoring many locations to capture the salient features of soil water in the field. The objective of this study was to examine whether there are temporally stable soil moisture patterns in a field and whether a representative moisture benchmark site can be identified from these patterns. The experiments were conducted on a black soil at Alvena, northeast of Saskatoon, Canada. Soil moisture was monitored at 95 measurement sites with a portable Capacitance Probe (CP) along a 612m rolling transect, from April to September in 2001and 2002. Temporal stability of spatial patterns in soil moisture for depths of 30, 60, 90, 120 and 160 cm were determined using temporal means and standard deviations of the differences between individual and spatial average values of soil moisture along the transect. The spatial patterns of soil water storage were stable in different locations for each depth. Contrary to reports in the literature clay content showed the least amount of control of spatial patterns. Coefficient of variation and standard deviation of soil moisture both decreased with increasing soil moisture. Soil moisture benchmark sites identified in this study represent field mean soil moisture and can be used for environmental monitoring and modeling

*Keywords:* Benchmark, Soil moisture, Spatial variability, Temporal stability

## Introduction

Soil water is the principle limiting factor in semi-arid agricultural production. Soil water also affects the transport of sediment, toxins and chemicals to environmentally sensitive areas such as surface water bodies and ground water. In addition to flowing water antecedent soil moisture has an effect on water infiltration, percolation to lower depths, runoff and evapotranspiration (Gómez-Plaza et al, 2000; Mohanty et al, 2000).

Soil water is influenced by topography, soil properties such as texture and vegetation, water routing processes, depth to water table and meteorological conditions (Western and Blöschl, 1999; Gómez-Plaza et al, 2001). The complex interaction of these variables can lead to large spatial heterogeneity of soil water and can vary greatly on field as well as point scales (Gómez-Plaza et al., 2000).

Due to the spatial variability of soil water in a field a complete picture requires numerous samples. Fortunately, the knowledge of the mean and variance are sufficient for most practical applications. Randomly taking a few dozen samples is one of the popular methods to obtain the average and variance of soil water. This method is not only time consuming and costly but the random nature precludes the return to the same sample point on consecutive occasions, making it difficult to study long term changes in field water regimes.

Benchmarking of soil water addresses the problems associated with random sampling. A benchmark site is a single reference point that is returned to for successive sampling. This point allows for comparative analysis of changes in soil properties. Traditionally, benchmark sites are selected because a site “looks” representative. This is quite arbitrary and selected sites may deviate from the average behavior of the field. There is a need for identifying benchmark sites that are representative of field average soil water content for agronomic and environmental applications.

Traditional sampling methods assume a random nature to spatial soil water variability, and can only provide estimates of field mean and variance. However, factors controlling soil water exhibit non-random patterns. Spatial patterns in topography, weather, soil, and vegetation within a field or catchment impact water flux patterns giving rise to patterns in soil moisture (Grayson and Western, 1998). These patterns of soil moisture may persist over time. To describe these time-persistent spatial patterns, Vachaud et al., (1985) introduced the concept of temporal stability, defined as the temporal invariance in the relationship between spatial location and statistical measure of soil moisture, most often the mean (Grayson and Western, 1998). Temporal stability was used as a method of reducing the number of sampling observations needed to characterize a field by Vachaud et al., (1985). An assumption is made that a point in the field will fall into a statistical rank and will keep that rank for subsequent measurements; therefore a point that represents the field average will continue to do so over a period of time (Vachaud et al., 1985). Vachaud et al., (1985) reported that temporal stability of soil moisture is realistic because the controlling factors such as soil texture and hydraulic properties affecting soil water are in themselves time stable.

There are no definitive criteria for selecting a benchmark site such that it represents the entire field mean and variance. There is conflicting information on what scale temporal stability exists and the factors controlling it. The research to date uses only a single depth for the measurement of soil water content or storage. A comprehensive study is needed to test if the conflicting conclusions are derived from discrepancies in depth measurements. In addition, there are no reports on selecting benchmark sites based on the concept of temporal stability. Therefore, the main objectives of this study are: (1) to identify whether there are time stable sites and if there are, whether time stable sites vary with depth; (2) whether it is possible to identify a time stable site from the readily measured soil and topographic properties; and (3) to determine if temporally stable sites can be used as benchmark sites.

## Materials and Methods

The study was carried out in a semi-arid area near Alvena, Saskatchewan, Canada. The site is located 70 km northeast of Saskatoon, on a rolling (slope class 4-3) field. The field is managed under a crop/fallow rotation and was under spring wheat in 2001, and left fallow in 2002 tilled using conventional methods. Nitrogen is typically applied during seeding at a single rate of 50 kg ha$^{-1}$. The annual precipitation averages around 350 mm, accumulating mostly as snowmelt in spring and rainfall in summer. With potential evapotranspiration reaching 624 mm per year water deficits can be as high as 274 mm. It was extremely dry in both 2001 and 2002; the total precipitation for the year 2001 was 159 mm (45% of long term average) while it was the driest year on record for Saskatchewan in 2002.

A soil survey was carried out in July, 2002. The field was formed on silty Glacio-lacustrine parent material comprised mainly of Orthic Black Chernozems, but also including Orthic Regosols on the knolls all belonging to the Blaine Lake association (Acton and Ellis, 1978).

A single, 612 m transect running North-South was monitored from April to September in both 2001 and 2002. The transect has 95 capacitance probe tubes spaced at six metre intervals and are installed to cover several knoll-depression cycles. The tubes for use with a Diviner 2000 were installed to a depth of 160 cm in the spring of 2001. Tubes were installed by removing a 160 cm soil core, of just slightly larger outside diameter than the tubes using a truck mounted hydraulic punch. Tubes were fitted with factory supplied installation guide which allow for installation to full depth without filling the tube with soil. 10 cm of tube was left above ground and the proper receptacle fitting was cemented into place.

Water content measurements were made using a capacitance probe (CP). Measurements were taken at least weekly and up to three times a week between April and September in 2002.

## Results and Discussion

Examples of spatial and temporal variations of soil moisture values (30 cm depth) for selected three dates (June 13, 2002, August 1, 2002 and July 20, 2002) at each probe location with respect to elevation are presented in Figure 1. These dates represent relatively moist, average and dry days respectively. In spite of the differences in average moisture, the measured soil water content or storage exhibited patterns; soil moisture values in the depression are higher than those on the knolls. Persistent dry conditions tend to homogenize spatial redistribution patterns. Note that to the far right (north) end of the field on the southern aspect moisture levels in depression area were lower than expected, most likely due to the south facing slope as well as drying winds originating in the south on hot days.

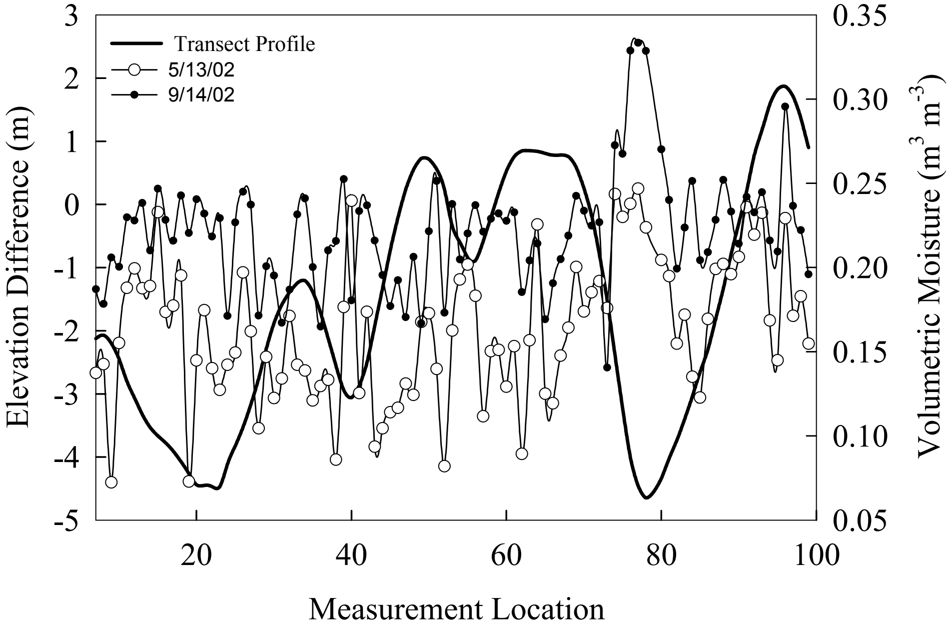

**Figure 1.** Moisture patterns for two days in relation to an exaggerated longitudinal profile (solid line, left axis) of studied transect.

Time-stable sites for soil water storage existed for the studied field. Figure 1 shows the standard deviations of mean relative difference for soil water storage at different depths. Sites that are close to the mean with corresponding small standard deviations were selected as time-stable sites, according to Vachaud et al (1985). A standard two-tailed t-test about the mean was then performed on the chosen sites. Sites that have a mean significantly different from zero are rejected as time stable sites at a 95% confidence interval.. Note that site eleven was the only site that occurred at two separate depths (Figure 2).

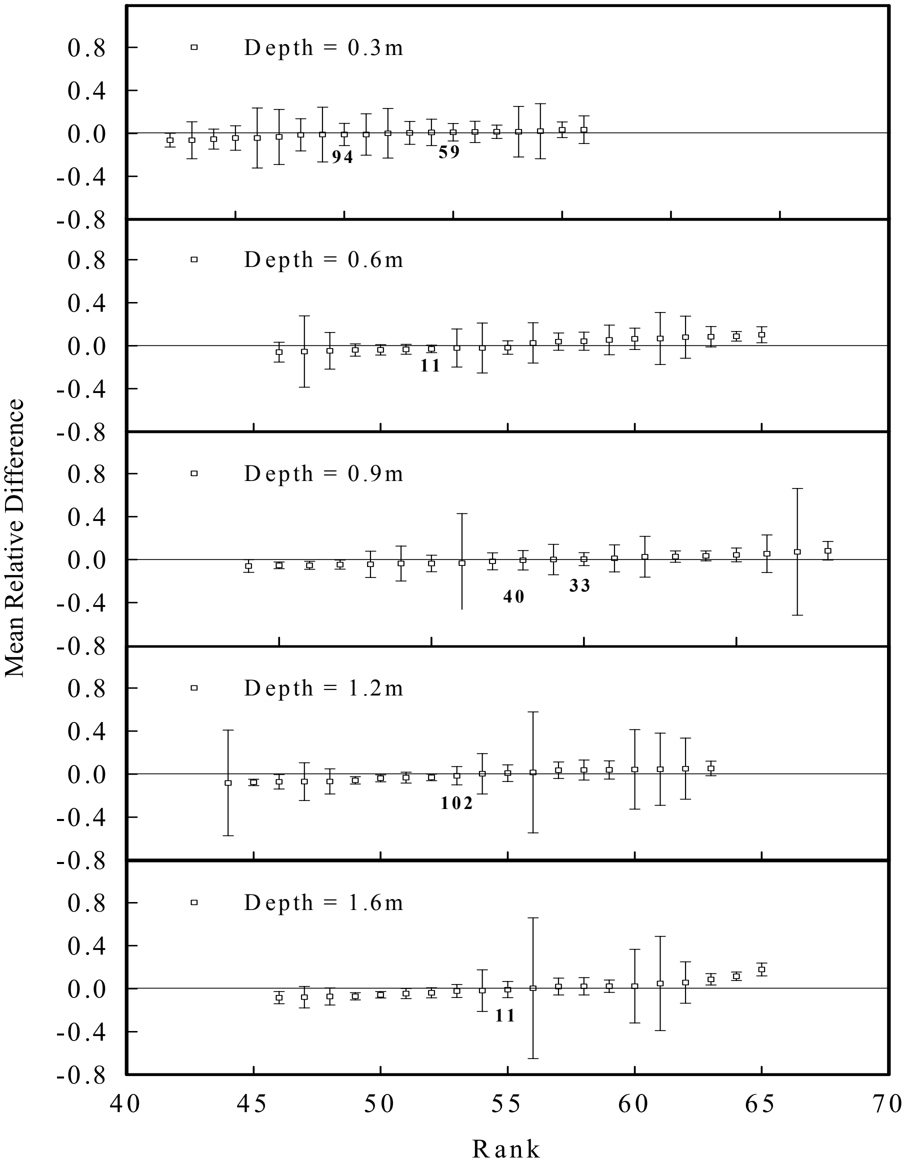

**Figure 2.** Ranked intertemporal relative deviation from the mean spatial water storage at 30 cm, 60 cm, 90 cm, 120 cm, and 160 cm depths. Vertical bars correspond to associated time standard deviation. Each point corresponds to a measuring location.

The finding of temporally stable sites is supported by others (Vachaud et al., 1985; Kachanoski and de Jong, 1988; Grayson and Western, 1998; Gómez-Plaza et al, 2000). Within the same field, time-stable sites can be different for various depths. For this study, point source time stable sites were located, while overall spatial patterns did not display consistent patterns. This is similar to Grayson and Western (1998) who found that transect scale temporal stability did not exist while point scale temporal stability exists because there was no spatial pattern that could be shown.

Temporal persistence of spatial patterns was examined for selected days using the Spearman's rank correlation (Table 1). The results show a good correlation with a high correlation coefficient of 0.70 between soil water storage measured on 13 June, 2002 and 14 September, 2002 and a low correlation coefficient of 0.36 between water storage measured on 24 July, 2002 and 14 September, 2002. The overall mean correlation coefficient is 0.54.

**Table 1.** Spearman's rank correlations illustrating persistence of spatial patterns.

| Day | 8/01/02 | 6/13/02 | 8/14/02 | 7/24/02 | 9/14/02 |
|---|---|---|---|---|---|
| 8/01/02 | 1 | 0.66 | 0.52 | 0.50 | 0.65 |
| 6/13/02 | | 1 | 0.56 | 0.49 | 0.70 |
| 8/14/02 | | | 1 | 0.46 | 0.50 |
| 7/24/02 | | | | 1 | 0.36 |
| 9/14/02 | | | | | 1 |

Variability for daily mean soil moisture values are presented in Figure 4. As the mean moisture content increases there is a corresponding decrease in the coefficient of variation (CV) while standard deviation (SD) remains constant. The exception to this is the increase in both CV and SD for the wettest point. This was the wettest mean recorded at 0.28 ($m^3m^{-3}$) and since there is just the single observation it is difficult to make inferences about an increase in variability.

There is very little correlation between soil water storage and any of the standard local (texture) and non-local (elevation, catchment area, wetness index, curvature) controls on soil moisture. Most surprising is a very weak correlation between texture and moisture storage, with a mean coefficient of determination of 0.02. On some days there was a good correlation between contributing area and storage. Contributing area showed the most consistent relationship on days that were relatively wetter, with coefficients of determinations ranging from 0.09 (6/21/02) to 0.25 (8/14/02), the exception being 0.03 on 6/26/02. Overall, on the drier days soil water storage has very poor relationships with all parameters. An exception existed for contributing area, which has coefficient of determination of 0.37 with soil water storage on 5/21/02. Water storage on this date also showed good relationships with elevation (0.186) and wetness index (0.18).

There was a consistent lack of dominance exerted by texture and topography. Overall coefficient of determination means for local and non-local controls were: texture (0.02) and non-local controls of elevation (0.065), contributing area (0.09), wetness index (0.047) and curvature (0.02) for 30 cm storage. This would suggest that not one single factor is responsible for the observed spatial patterns. Contributing area, a non-local control, is most consistent in explaining patterns. This is reasonable because in the prairie region the most significant recharge and redistribution event is the spring snowmelt. Recharge preferred states are characterized by non-local controls (Grayson et al., 1997). Contributing area, a non-local control, reflects the upslope area contributing runoff of snowmelt to a point. Conversely, water loss during the summer months is governed by evaporation. Evaporation is controlled by temperature, humidity and wind speed. In sheltered depressions relative to knolls, humidity gradients and wind speeds are lower. Therefore, in depressional areas, evaporational losses will not be as great as knoll positions. Evaporative losses are indirectly related to contributing area and elevation in that the greater the contributing area and lower the elevation, the further downslope a point is. Therefore depressions are subject to less evaporative demand relative to the knoll. This may serve to explain why contributing area exhibited the most consistent control on water storage.

The use of differing depths in identification of temporal soil moisture stability is not widely studied. There is a lack of research on the finding of time stable depths and their relation to the most commonly studied soil variables. Grayson and Western (1998) reported that there were no significant effects of measurement depth between measured data sets. Our results have shown that there were substantial differences in measurement depths, and the sites were not even adjacent in terms of spatial location. Since semi-arid water redistribution is dominated in summer months by vertical flow with little connection between points (Gómez-Plaza et al, 2001), then it should follow that deeper time stable depths should be located in relative proximity to the overlying sites. Once again this is not the case and more research is needed to elucidate the soil controls on various time stable depths.

There is no discernible pattern along the transect with respect to occurrence of these sites. Time stable sites occurred on both north and south aspects and were also found on shoulder, mid and low slope positions. Grayson and Western (1998) expected that sites that represent field means should be found in field neutral locations, including slope and aspect. This was not the case in this study. While slope aspect does have an effect on moisture levels in the field we studied, especially at the northern end of the field with a south face, where the slope is quite steep, aspect does not seem to be the dominant control. Temporally stable sites occur independent of slope aspect and slope position.

Gómez-Plaza et al., (2001) found that moisture patterns could be explained by soil texture. Mohanty et al., (2000) state that soil texture will dominate control on soil water in the mid to low water pressure range and in the absence of vegetation. The results from this study are not in agreement with their findings as there was a lack of relationship between moisture in the first 30 cm and texture, specifically clay content. We found a very weak correlation between clay content and soil moisture patterns. In support of this are Si and Farrell (2003). In their 2001 study there was a poor correlation between crop yield and soil texture for a dry year. This would also indicate a poor relationship between soil water and texture. The evidence is suggestive that drought conditions were severe enough to minimize the control of texture and non-local controls on time stability of soil moisture storage. Although clay content varied by around 30% at some points, the textural class only ranged from silty clay loam to silty clay, with the majority of the field being silty clay loam. It is cautiously suggested that even with fluctuations in clay content, silt content served to smooth out variations and homogenize the field in terms of textural class. This may serve to lessen the control that texture would have on spatial patterns.

## Conclusions

A representative soil water benchmark site has the potential to provide important information for environmental monitoring. Temporally stable spatial patterns within the field led to the determination of benchmark sites for various depths that were representative of field mean soil moisture. Time stable sites showed poor relationships to soil and topographic properties suggesting the absence of a single dominant control. The most consistent control was catchment area, a non-local control indirectly affecting evaporative losses. Future studies should look at the effect of controls on all depths in an effort to determine time stable sites *a priori* as well as upscaling of point source temporal stability. Benchmark sites whether they represent mean or extreme values can greatly improve sampling efficiency and can provide useful information for environmental monitoring.

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