Representative Benchmark Site Identification for Soil Moisture Storage

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Abstract

Soil moisture limits agricultural production in semi-arid prairies and is a key hydrological factor affecting the fate and transport of pollutants in soils. Spatial and temporal variability in soil water 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, northwest 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 2001 and 2002. Temporal stability of spatial patterns in soil moisture for depths of 30, 60, 90, 120 and 160cm 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. Spatial variations in soil moisture with daily soil moisture means of >0.20 and <0.20 showed poor correlations with soil texture ($R^2 < 0.1$) and topographical variables ($R^2 < 0.3$). Clay content showed the least amount of control of spatial patterns with only one day with R^2 (=0.08) greater than 0.01. Coefficient of variation and standard deviation of soil moisture both decreased with increasing soil moisture. For depths of 30, 90, and 120cm, benchmark sites had a difference of less than 1% in soil moisture storage from both measured field mean and a composite sample obtained using the conventional random sample method, indicating the three methods are equivalent to each other. Soil moisture benchmark sites identified in this study represent field mean soil moisture and can be used for fertilizer recommendation and environmental monitoring.

Introduction

Soil water is the principle limiting factor in semi-arid agricultural production and a key element in environmental health. The movement of water through the soil will affect the transport of sediment, toxins and chemicals to environmentally sensitive areas such as surface water bodies and ground water and has a direct impact on crop yield. Soil water is influenced by topography, soil properties such as texture, vegetation, water routing processes, depth to water table and meteorological conditions (Gómez-Plaza et al, 2001; Western and Blöschl, 1999). 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).

Because of the spatial variability of a field, monitoring soil water or making fertilizer recommendations requires representative sampling. Sampling methods could be either completely random or a biased system where certain areas are avoided such as knolls, depressions and headlands. One of the popular methods is random sampling, taking 20 to 30 samples from the field to determine soil moisture content. Not only are these methods time consuming and costly, the random nature precludes the return to the same sample point on consecutive occasions, making it difficult to study long term changes in fertility and water storage.

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. Once their location is determined, these sites will yield a representative trend of the field as opposed to intensively sampling random spots in the field. This would allow for long term monitoring and evaluation of effects the particular soil management practices on soil quality and crop production.

Benchmark sampling has been adopted for soil fertility monitoring. However, benchmark sampling does not currently provide information on soil water storage, which is important parameter affecting soil fertility. There are no definitive criteria for selecting a benchmark site. Further, majority of the farm field still using uniform rate of fertilizer application. There is a need for identifying benchmark sites that are representative of the field average. We call these benchmark sites representative benchmark sites.

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.

Objectives

There are a limited number of reports on benchmarking (Keyes and Gillund, 1995, Keyes et al., 2001), mostly dealing with nutrients. However, there are no reports on how to identify representative benchmark sites. The idea of returning to a single point or small group of points in a field to determine values representative of field mean soil moisture is an attractive one to both research and industry. We hypothesize that there are temporally stable spatial patterns in the field and a time stable site that represents the average soil moisture in the field. The main objectives of this study were (1) to identify whether there are time stable sites and if there are, whether time stable sites vary with depths; (2) whether it is possible to identify a time stable site from the readily measured soil and topographic properties; and (3) to compare uncertainty associated with a benchmark site as well as with conventional random sampling in terms of fertilizer recommendations.

Materials and Methods

The study was carried out in a semi-arid area at Alvena, Saskatchewan, Canada. The site is located 70km northeast of Saskatoon, on a rolling (slope class 4-3) field. 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 all belonging to the Blaine Lake association (Acton and Ellis, 1978). The soils were classified from cores taken by a truck-mounted hydraulic punch and classified based on the Canadian System of Soil Classification (Soil classification working group, 1998). Texture analysis was performed using the simplified hydrometer method (Gee and Bauder, 1979). The average texture is that of a silty clay loam with an A horizon averaging 11cm. A-horizon depth ranges from below 90cm in the deepest depression to non-existent on the knolls. A single 612m transect, running North-South was monitored from April to September in both 2001 and 2002. Measurements were taken at least weekly and up to three times a week between April and September in 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.

Results

Temporally Stable Sites

Time-stable sites for soil water storage existed for the studied field. This conclusion is supported by others (Gómez-Plaza et al, 2000; Grayson and Western, 1998; Kachanoski and de Jong, 1988; Vachaud et al., 1985). The temporal stability of soil moisture for spring days was examined. Figure 1 shows the standard deviations of relative difference for soil water storage at 90cm. Sites that are close to the mean with corresponding small standard deviations were selected as time-stable sites, according to the method used by Vachaud et al (1985). A standard two-tailed t-test about the mean was then performed on the chosen sites. Sites that did not fall within a 95% confidence interval were subsequently rejected. Within the same field, time-stable sites can be different for various depths. The temporally stable sites that we located represent a middle ground between those found by Gómez-Plaza et al., (2000) and Grayson and Western (1998). In the first case temporal stability was found at field scales in that the sites that were chosen closely represented the mean and retained their statistical rank for the entire field. Since these sites retained their rank within their respective depth it is expected from Gómez-Plaza et al, (2000) that there will be a pattern at the transect scale. In their study Gómez-Plaza et al, (2000), found that there was transect scale time stability and moisture patterns were retained for a bare field. 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 existing on the point scale because there was no spatial pattern that could be shown.

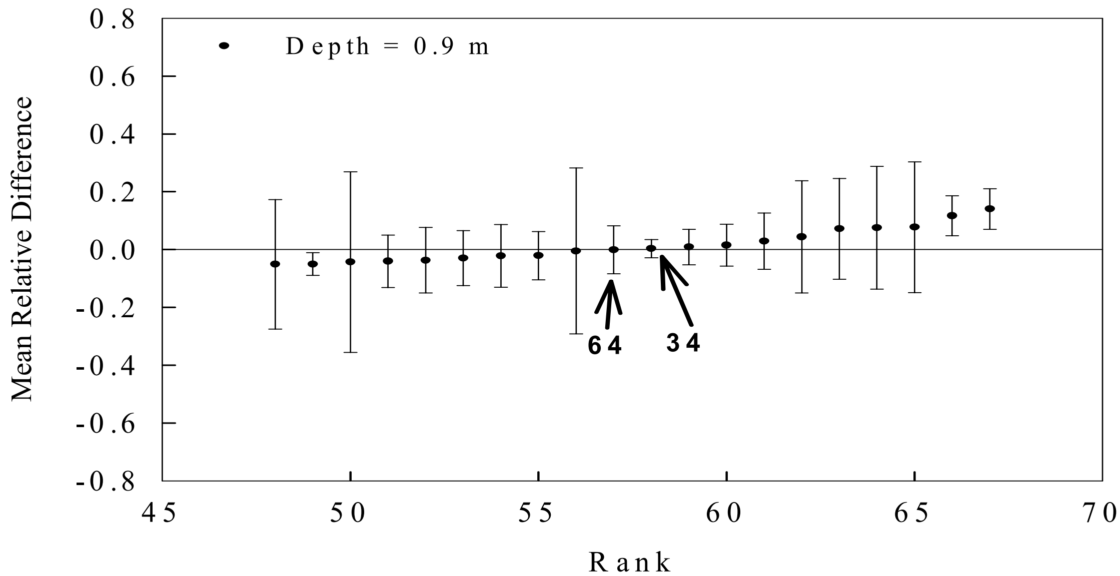

Figure 1. Temporally stable measurement points for 90 cm depth.

Temporally Stable Depths

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 significant differences in measurement depths, and the sites were not even adjacent in terms of spatial location. Since semi-arid water redistribution is dominated 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.

We found a very small 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. In a 2001 study Pennock et al. reported that in years of average soil moisture redistribution is controlled by surface and lateral flow and there exists a clear distinction between landform positions. In years of below average precipitation similar to the one studied here, differences between landform positions can narrow or vanish completely (Pennock et al., 2001). It is the disappearance of these differences that lead to the lack of control from texture and the overall contribution of all factors.

Uncertainty in benchmarking

Agronomists stand to benefit from the successful identification of a soil moisture benchmark site. Measurement at a single location significantly improves efficiency when assessing spring soil moisture. Spring soil water storage is strongly related to spring wheat yields. (Walley et al., 2001). For the spring of 2002, only four days contributed to the determination of temporally stable sites. Therefore it was felt that the persistence of the spatial pattern was inadequately influenced by the spring days to confidently determine spring benchmark sites. It was then decided to determine a set of time stable sites for spring soil moisture measurements specifically with yield predictions in mind.

From yield predictions, fertilizer rates can be recommended. For an average field, the prospect of higher yields will mean a higher rate of fertilization to a point of maximum economic returns. Walley et al. (2001) stated that moisture deficits will limit the positive effects of fertilization and cannot fully compensate for inadequate soil moisture. It is important, therefore, to have an accurate representation of mean soil water.

In order to maximize productivity, a benchmark site must accurately represent mean soil water. There is a measure of uncertainty involved in using one sample to represent up to 30. To assess the uncertainty involved with the benchmarks sites a comparison was made to a mock conventional biased sample and the actual measured field mean. The mock samples were not taken in the field but at midslope points from the data already obtained. A total of eight samples were taken and averaged in an attempt to mimic how a conventional representative sample would be taken. Results from May 6, 2002 are compared in Figure 2.

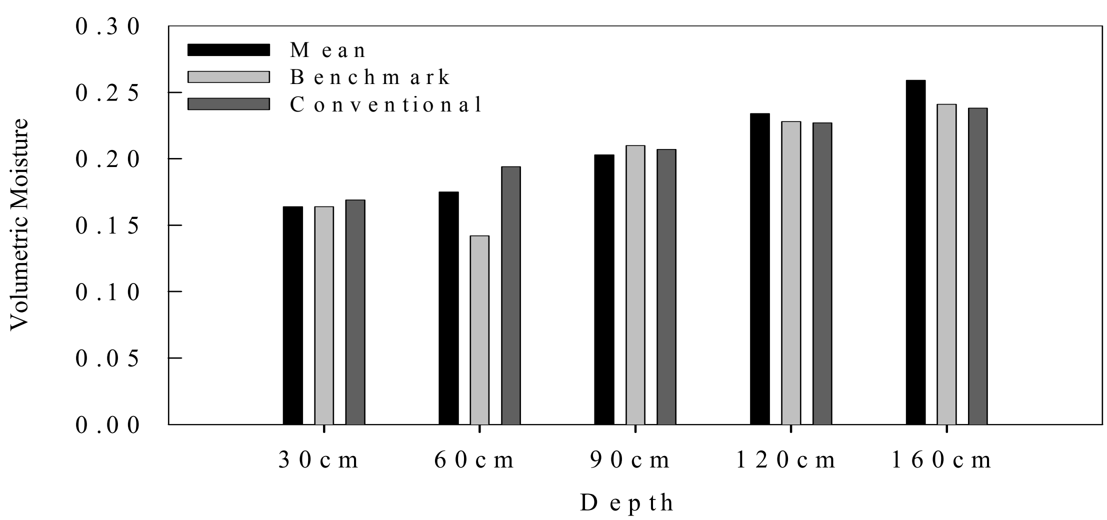

Figure 2. A comparison of the benchmark sample to actual field mean and conventional sample.

As can be seen from Figure 2, the differences between the benchmark and conventional samples were small indeed. Assuming a 1% measurement error it can be said that the measured field mean and benchmarksamples are identical.

Conclusions

A representative soil water benchmark site has the potential to provide important information for crop production and environmental health. 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. Benchmark sites for four days in May were very close in comparison to the actual field mean and to a conventional sample. This indicates that the sites are representative of the entire field and when within an assumed 1% sampling error acceptably represents the field mean. 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 to a spatial scale closer to that of a seeder. Benchmark sites whether they represent mean, extreme or threshold values can greatly improve sampling efficiency and can provide useful information for agronomic decisions and environmental monitoring.

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