# The relationship between field soil water content variability and soil moisture deficit prediction from meteorological data

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**Abstract**
The Hybrid Soil Moisture Deficit (SMD) model (Schulte *et al*., 2005) was designed to predict soil moisture conditions as a function of water balance for agro-climatic regions in Ireland. It is assumed to work between the field scale (1,000 $m^2$) and the regional scale (100 $km^2$) and is being developed to predict runoff at the field scale. However soil physical properties that affect the water balance vary significantly at field scale. This study provides preliminary evidence of how a point estimation of SMD can be used as a predictor of a field water balance. Point SMD predictions calculated from meteorological data measured on farm were compared with continuous time series point volumetric water content ($\theta_p$) and periodic observations of variation in field volumetric water content ($\theta_f$) both measured by time domain reflectometery. The $\theta_p$ and $\theta_f$ trends were relatively similar.

**Key Words**
Soil, water, model, prediction, spatial, drainage

## Introduction

The Hybrid Soil Moisture Deficit (SMD) model (Schulte *et al*., 2005) was designed to predict soil moisture conditions as a function of water balance for agro-climatic regions in Ireland. It is a point model because it uses input data from a specific meteorological observation location; however it has always been tacitly assumed that it predicts water balance over an unspecified spatial extent thought of as a "field". Additionally, the model is effectively dimensionless with no defined support (i.e. defined length, width and depth over which it functions). It was not designed to predict soil water contents, rather to predict when the soil was at a state of wetness, expressed relative to field capacity, with units of mm rainfall deviation from field capacity. Furthermore, the model has potential as the basis of farm decision support tools because it requires little data to run (soil classified into one of three classes, rainfall, wind speed, temperature and solar radiation), yet during development gave reliable predictions of relative soil water status for a range of grassland fields.

The SMD model is being developed as the core of a demonstration sustainable nutrient management decision support system. As part of its testing and development, it is necessary to understand more about the spatial scale over which the model applies, and how point predictions relate to field scale spatial variability on the farm. As it was not designed as a physical model, soil variations are captured via 3 operational drainage classes: well, moderate and poorly drained. Although a field is assigned to a class, two drainage classes may occur in the same field, so it is imperative to ensure that each area of a field is allocated to the correct class. For practical purposes, it has been decided that the minimum area to be considered will be 4,000 $m^2$, which equates to the area of spreading for one full slurry tanker. Although the weather is a main factor affecting nutrient transport from the field to watercourses, the soil physical properties can also have a large impact on leaching and runoff events.
The objective of this work was to evaluate the relationship between Time Domain Reflectometry (TDR) estimates of soil volumetric water content ($\theta_p$) at a fixed location associated with the farm weather stations, spatial variability $\theta_f$ of water content in the field, and point prediction of SMD on the farm weather stations.

## Methods

*Sites*

Ten sites representative of the three grassland soil drainage classes were selected to evaluate the SMD model and the larger decision support system as a whole. They were selected based on geographical distribution (north to south climate gradient) and the range of drainage classes they encompassed. For this paper, examples from two sites are presented representing poor and well drained soil classes.

*Soil moisture deficit calculation*
Meteorological stations were installed at each site therefore weather data from synoptic stations, interpolation or Numerical Weather Prediction (NWP) were not required. Daily SMD was calculated from weather data using maximum and minimum temperature (°C), rainfall (mm), wind speed at 10m (m $s^{-1}$) and radiation (J $cm^{-2}$) on a daily basis. The SMD model also requires spatial co-ordinates (latitude and longitude) and previous SMD state (the model is initialised in mid-winter to ensure wet soil conditions). In the past it has been found that the SMD model relates best to a 15 cm tensiometer, which represents rooting zone in a grassland soil.

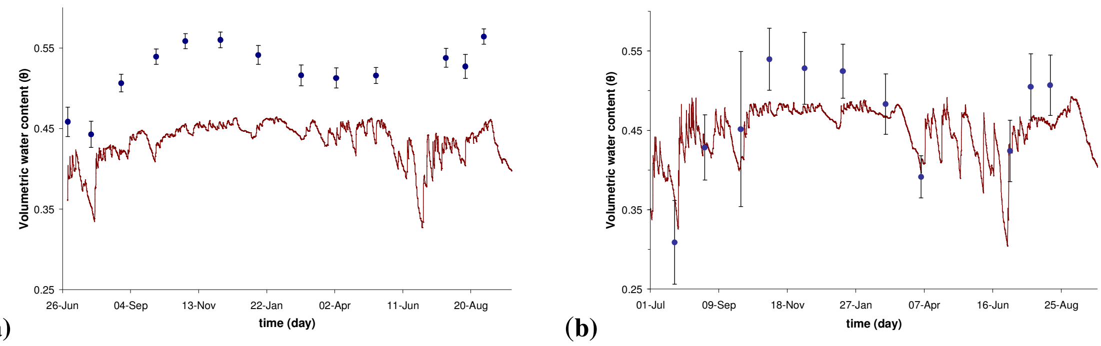
*Volumetric water content (θ)*
In order to evaluate SMD predictions, the point soil volumetric water content ($\theta_p$) was measured by a time domain reflectometer (TDR) at fixed locations relative to the weather station. Four continuously logged TDR probes were inserted into the wall of two pits. Each pit has one probe inserted at 10 cm and another one at 20 cm and at least 24 cm apart.

The spatial variation in soil water content ($\theta_f$) was assessed on specific days by handheld TDR. Waveguides 12 cm long were used to measure the volumetric water content across the soil surface. Variation in $\theta_f$ was then compared to $\theta_p$ and maps were created to visualise how representative the fixed TDR was of the sites being used to test the DSS.

Handheld and fixed time domain reflectometers were calibrated by collecting volumetric water content samples for laboratory analysis. Soil samples (3 × 13.7 $cm^3$ at 10 cm and 20 cm depths ) were taken on a monthly basis during visits to each site. These samples were dried at 65°C until the dry mass was constant and the volumetric water content was calculated as the mass of water per unit volume soil sampled.

## Results

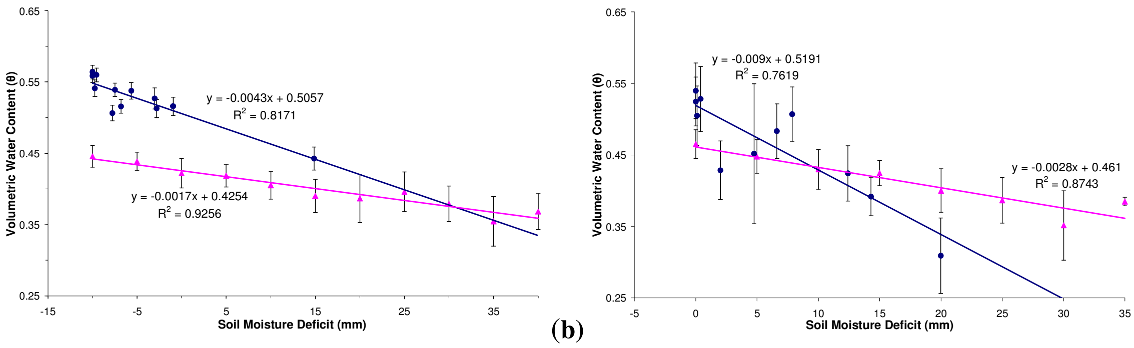
Although the volumetric water content, $\theta$, has not been determined for the soil surface, the soil surface $\theta$ and the TDR $\theta_p$ at 10cm depth have the same trends but slightly different absolute values (Figure 1). It can be expected that the soil surface will have a more rapid change in $\theta$ than at 10 cm depth: on the well-drained soil, the soil surface is drier or wetter than at 10 cm depth on respectively drier or wetter periods of the year; on the poorly-drained soil, the soil surface usually remained wetter than at 10 cm depth but the $\theta$ range was much greater at the soil surface than at 10 cm.




(a) (b)

**Figure 1. The volumetric water content over 13 months on a poorly-drained soil (a) and a well-drained soil (b) in Ireland. Fixed TDR time series are measured on a daily basis (-) while field observations with standard deviation of spatial variation (●) are made on a monthly basis.**

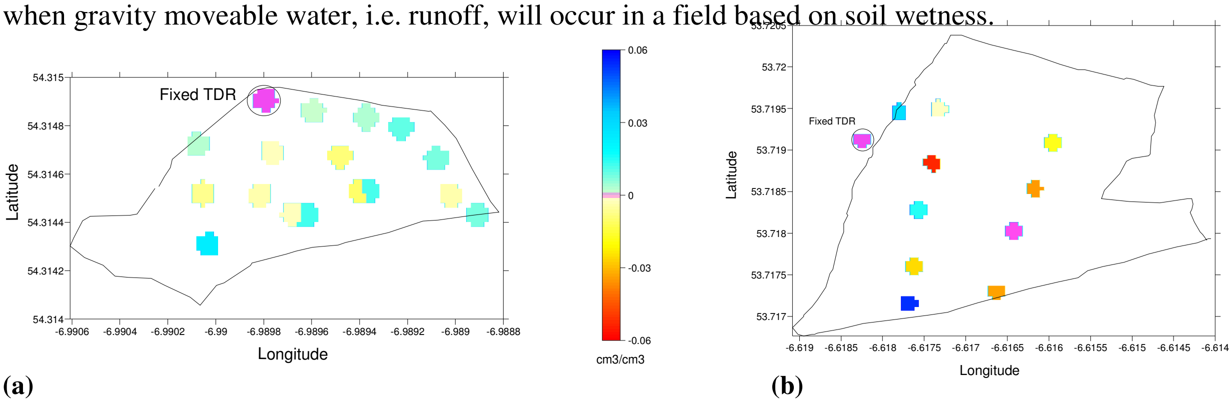
At a given location, SMD prediction was related to volumetric water content measurement, $\theta$ (fixed TDR or handheld TDR). On average, at a given point, the linear regression of $\theta_p$ and SMD was significant if SMD data were grouped into classes of 5 mm (Figure 2). This means that small differences in SMD were smoothed out. The linear regression of mean of $\theta_f$ and SMD was also significant (Figure 2). However, the standard deviation was much larger for the well-drained soil than for poorly-drained soil, perhaps due to differences in soil depth or topography at the sites.




(a) (b)

**Figure 2. Comparison of soil moisture deficit (mm) predictions with soil volumetric water content ($cm^3H_2O/cm^3$soil) measurements (by fixed TDR (▲) and by handheld TDR(●)) on a poorly-drained soil (a) and a well-drained soil (b).**

Even though the SMD model is effectively dimensionless, SMD predictions were good estimates of the soil wetness. In addition to comparing $\theta$ versus SMD, the spatial variation of $\theta$ was also considered. These data showed that soil moisture variations at the field scale were small (Figure 3). However the application of the SMD model to some areas should be considered carefully. While it is recognised that these example fields do not capture all variability that might be found on grassland farms, these preliminary data do indicate that the SMD model should be able to correctly capture trends in soil water balance, thus permitting a forecast of when gravity moveable water, i.e. runoff, will occur in a field based on soil wetness.




(a) (b)

**Figure 3. Volumetric water content variation ($\theta$) across the field on a poorly-drained soil (a) and a well-drained soil (b).The colour scale represent the average difference of volumetric water content between the fixed TDR location and other points (blue is wetter and red is drier).**

## Conclusions

It was found that:

- The trend in $\theta$ was similar for the point observation and the mean of the field observations over time. This means that the point field observation is characteristic of the field it represents, but that absolute value does not necessarily reflect all that might be happening in the field.
- SMD and $\theta$ were significantly related. While SMD is not a prediction of $\theta$ it is necessary that it reflects the trend in $\theta$ correctly in order to give confidence to the use of SMD to predict when a condition of gravity moveable water exists in a field.
- Small changes in SMD are probably not that meaningful at the field scale. SMD classes of 5 mm were required to clearly see trends between SMD and $\theta$.
- The relationship between SMD and $\theta$ was different at the surface as a spatial average (as measured around the field) when compared at a given location in the field. This reflects the fact that the SMD model is a mixing bucket model that works over a non-defined depth. The trends indicate that the SMD model should work at the farm scale.

## References

Schulte RPO, Diamond J., Finkele K, Holden NM and Brereton AJ (2005) Predicting the soil moisture conditions of Irish grasslands. *Irish Journal of Agricultural and Food Research* **44**, 95-110.