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SPATIAL MAPPING OF ROOT ZONE WATER HOLDING CAPACITY FOR SITE-SPECIFIC MANAGEMENT

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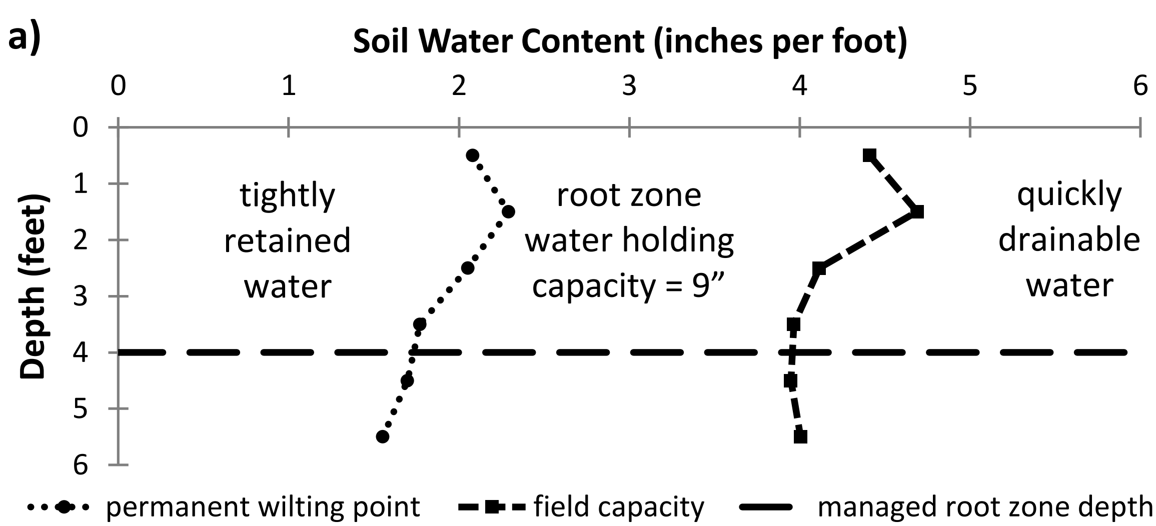
CONCEPTS

Definition of Root Zone Water Holding Capacity

Root zone water holding capacity (*R*) is the total amount of water that is available to the crop from a full soil water profile. Not every drop of water between the soil surface and maximum root depth is available to crops. For irrigation management of agronomic crops in the Central Plains, producers are typically advised to consider only the soil water within the managed root zone, which is the upper portion of the total root zone where most roots and most root water extraction generally occur. Once the root systems of these crops are assumed to be well-developed, the managed root zone is commonly estimated as the top two to four feet of soil. Also, water in excess of field capacity is expected to drain out of the managed root zone within one to three days due to gravity. Water below permanent wilting point, on the other hand, is not expected to be extractable by plant roots because this water is held too tightly by soil pores. Therefore, *R* is calculated as the difference between field capacity and permanent wilting point over the managed root zone (fig. 1).



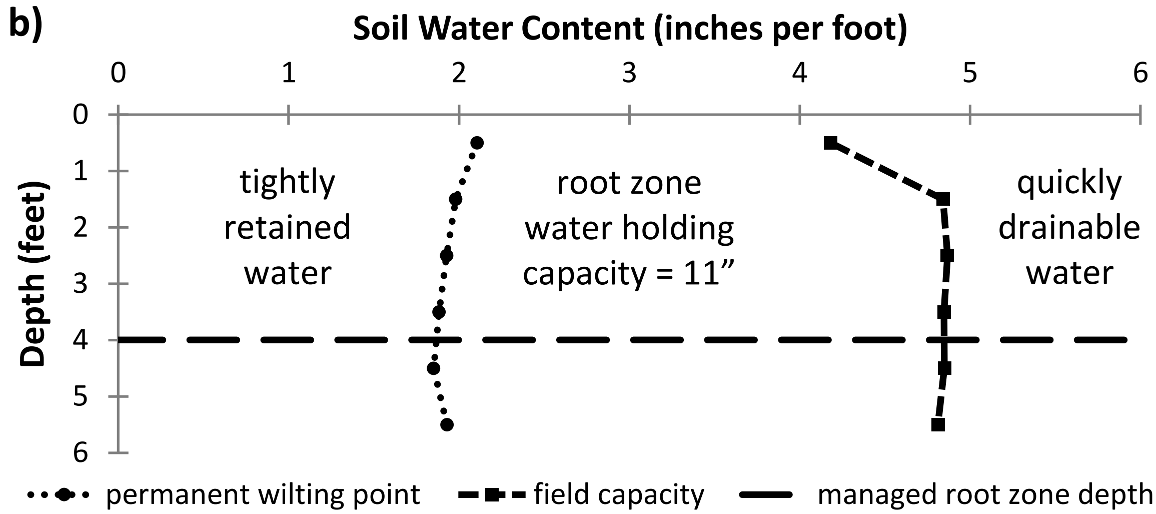


Figure 1. Average root zone water holding capacity a) at the top and b) at the bottom of the slopes in the field site.

Relevance of Root Zone Water Holding Capacity to Site-Specific Management

With conventional (i.e., non-site-specific) irrigation (CI), understanding the spatial distribution of *R* may inform and improve management decisions, but mapping *R* is not essential for managing CI. Irrigation scheduling strategies based on soil moisture often use just one value of *R* to evaluate when a field should be irrigated with CI. This value of *R* is usually selected to represent either the majority of the field or the field areas with the smallest *R*.

With variable rate irrigation (VRI), however, quantifying *R* throughout the field may be a priority. As spatial variability in *R* can be a main cause of spatial differences in crop response to irrigation, consideration of *R* can be beneficial when creating management zones and when customizing irrigation applications for each management zone. The depleted fraction of *R* is frequently used to estimate the magnitude of crop water stress severity (Merriam, 1966; Allen et al., 1998; Steduto et al., 2009), and recommendations have been offered regarding the ranges of the *R* depletion fraction to be maintained for optimal yield of various crops. One VRI management strategy aims to maintain the *R* depletion fraction in each management zone just above a common threshold (Ritchie and Amato, 1990; Nijbroek et al., 2003; King et al., 2006; Hedley and Yule, 2009). According to this strategy, soil water content would be kept closer to field capacity in areas with smaller *R* and kept farther from field capacity in areas with larger *R* (fig. 2). The retention of in-season rainfall is consequently maximized, which enables reductions in the water and energy expenses of irrigation and decreases in the leaching of contaminants into groundwater. This strategy, furthermore, may improve yield quantity and/or quality of crops for which maintaining soil water content near field capacity is detrimental (Grimes et al., 1969; Matthews and Anderson, 1988). Also, where off-season precipitation can be significant, managing VRI to leave the same *R* depletion fraction in each management zone at the end of the growing season may increase the natural recharge of soil moisture during the off-season (Lo et al., 2015). To achieve the potential benefits of the aforementioned VRI management strategies, spatially and numerically accurate *R* data is needed.

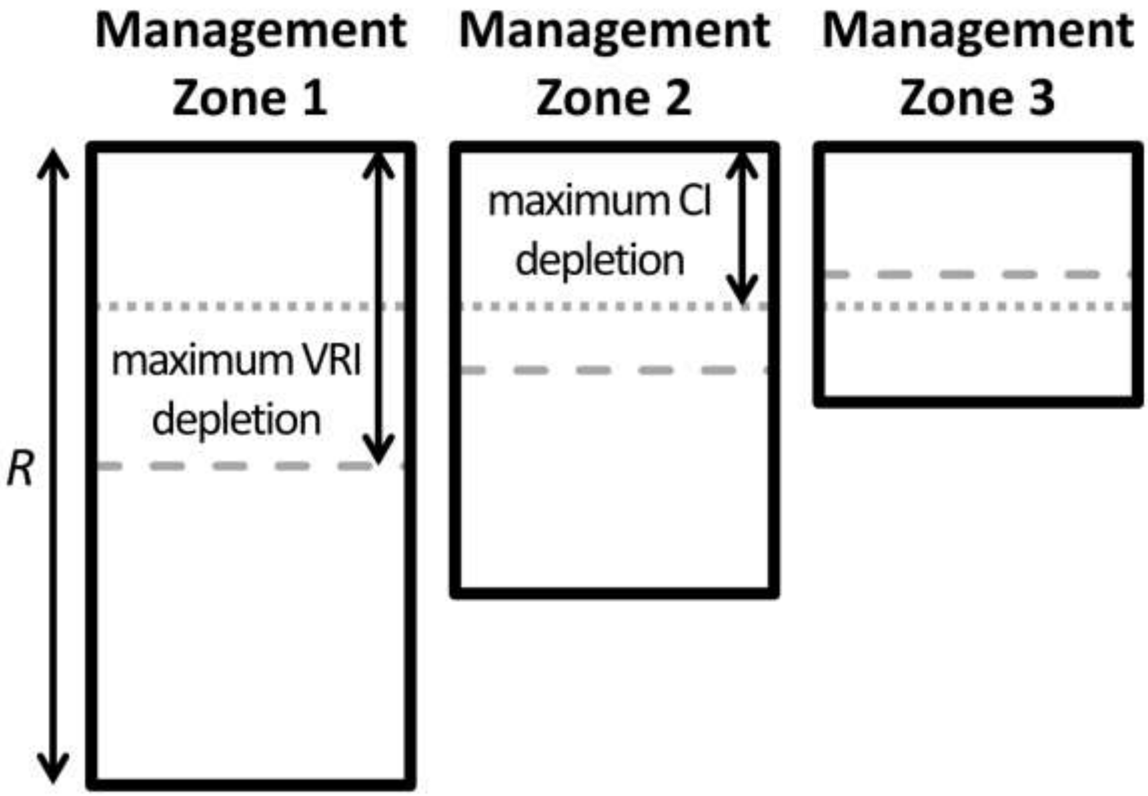


Figure 2. Possible differences between conventional irrigation (CI) and variable rate irrigation (VRI) in terms of the maximum depletion of root zone water holding capacity (*R*) that is accumulated before the next irrigation application.

As a side note, *R* is likely to be also relevant to non-irrigation aspects of agronomic management for both irrigated and rainfed agriculture. For instance, an *R* map may be beneficial for deciding variable seeding and fertilizer rates.

Approaches to Mapping Root Zone Water Holding Capacity

The authors are not aware of an on-the-go sensor that directly measures *R*. Instead, field capacity and permanent wilting point are generally determined at multiple sampling locations (further details in "Sampling Methods" subsection), whereas the depth of the managed root zone is typically assumed. With the *R* data for these sampling locations, an *R* map is then created using one of two approaches.

The more straightforward mapping approach estimates the *R* value at an unsampled location as the weighted average of the *R* values at neighboring sampling locations. Though successful in past research (Haghverdi et al., 2015a), this approach requires a high density of sampling locations, which might be prohibitively expensive.

An alternative approach relies on predictor variables that are more affordable to measure densely than *R* itself. First, the relationship between the predictor variable(s) and *R* at the sampling locations must be identified. Subsequently, the identified relationship can be applied to predict the

R value at an unsampled location based on the known value of the predictor variable(s) at those locations. The most common implementation of this approach involves linear regression between apparent soil electrical conductivity (EC_a) and *R* (Wong et al., 2006; Hezarjaribi and Sourell, 2007; Jiang et al., 2007). Yet, any densely measured variable representing a cause or an effect of spatial variability in *R* can be a justifiable predictor variable for *R* and—depending on the field of interest—may even relate more closely to *R* than EC_a does. Other predictor variables that have been assessed in past research include rainfed yield (Morgan et al., 2003), irrigated yield, and satellite panchromatic brightness value (Haghverdi et al., 2015b).

CASE STUDY

Field Site

Root zone water holding capacity (*R*) was mapped on a private farm field in Hamilton County of south central Nebraska (fig. 3; Lo, 2015). Corn-soybean rotation and north-south ridge tillage were generally practiced on this field. The half-circle center pivot system irrigated 56 acres with a maximum elevation difference of 39 feet. A total of 32 sampling locations were selected along two pairs of transects that each extended down into an ephemeral stream valley.

Figure 3. Root zone water holding capacity (*R*) map of the field site.

Sampling Methods for Root Zone Water Holding Capacity

In this study, the depth of the managed root zone was assumed to be four feet throughout the field, which seems to be reasonable for corn.

The standard method for measuring field capacity is to saturate the soil profile, cover the land surface to prevent evapotranspiration, and monitor the gradual decline in soil water content (Romano and Santini, 2002). In this study, however, the soil water content at the sampling locations on June 18th, 2014—two to three days after 1.1 inches of rain and near the end of a wet period—was chosen as an approximation of field capacity at those locations. Similar approximations have been made or recommended in past research (Martin et al., 1990; Morgan et al., 2003; Jiang et al., 2007; Haghverdi et al., 2015a). Practitioners can measure soil water content by oven-drying intact soil cores that have been extracted using a hydraulic soil sampling probe.

The standard laboratory method for measuring permanent wilting point is the -15 bar pressure plate. In this study, however, a pedotransfer function developed by Saxton and Rawls (2006) was used to estimate the -15 bar soil water content at the sampling locations based on several soil properties (i.e., percent sand, percent clay, percent organic matter, and bulk density). Pedotransfer functions have been used to estimate permanent wilting point in past research as well (King et al., 2006; Haghverdi et al., 2015a). Practitioners can acquire soil composition data by sending soil samples to a soil testing laboratory. The oven-drying of intact soil cores for determining field capacity also provides the necessary information for calculating bulk density.

Except at the top of the slopes, the field capacity estimates obtained in this study were clearly higher than the values in the soil survey (NRCS, 2015) and the one-third bar soil water content estimated by the Saxton and Rawls (2006) peodtransfer function. On the other hand, the permanent wilting point estimates obtained in this study were comparable to values in the soil survey (NRCS, 2015).

Selection of Predictor Variable for Root Zone Water Holding Capacity

Shallow apparent soil electrical conductivity (EC_a), deep EC_a, the ratio of shallow to deep EC_a (Kitchen et al. 2005), and elevation were compared in terms of their respective suitability as the predictor variable for *R* on this field. Among the four choices, elevation was found to relate most closely to R at the 32 sampling locations. Therefore, a piecewise polynomial regression equation was fitted to the *R* versus elevation data from the sampling locations (fig. 4). The equation was then applied to the entire area beneath the half-circle center pivot to produce an *R* map (fig. 3).

Sampling Locations for Root Zone Water Holding Capacity

The optimal number of sampling locations and the optimal placement of these locations are field-specific and may be difficult to predict. Nonetheless, if the predictor variable for *R* has been selected, then sampling schemes can be designed to provide adequate coverage over the full range of the predictor variable. Such a sampling scheme with five sampling locations was simulated. The fitted piecewise polynomial regression equation for these five data points was found to be comparable in accuracy to the fitted piecewise polynomial regression equation for all 32 data points.

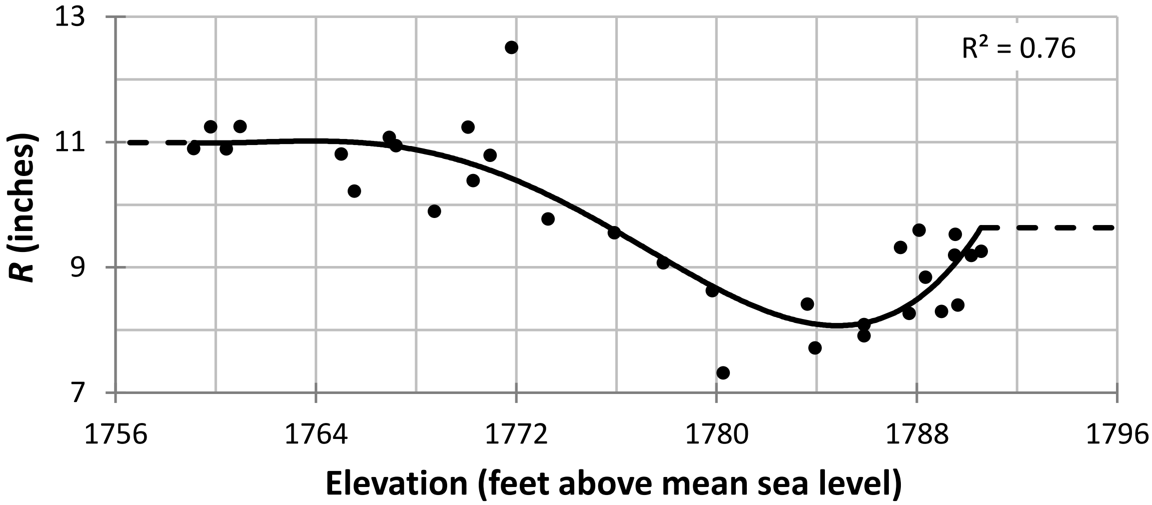


Figure 4. Relationship between elevation and root zone water holding capcity (*R*) at the 32 sampling locations in the field site.

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