COMPARISON OF SOIL WATER SENSING METHODS FOR IRRIGATION MANAGEMENT AND RESEARCH

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ABSTRACT

As irrigation water resources decrease and deficit irrigation becomes more common across the Great Plains, greater accuracy in irrigation scheduling will be required. With deficit irrigation a smaller amount of soil water is held in reserve and there is less margin for error. Researchers investigating deficit irrigation practices and developing management practices must also have accurate measures of soil water content – in fact, the two go hand in hand. New management practices for deficit irrigation will require more accurate assessments of soil water content if success is to be ensured. This study compared several commercial soil water sensing systems, four of them based on the electromagnetic (EM) properties of soil as influenced by soil water content, versus the venerable neutron moisture meter (NMM), which is based on the slowing of neutrons by soil water. While performance varied widely, the EM sensors were all less precise and less accurate in the field than was the NMM. Variation in water contents from one measurement location to the next was much greater for the EM sensors and was so large that these sensors are not useful for determining the amount of water to apply. The NMM is still the only sensor that is suitable for irrigation research. However, the NMM is not practical for on-farm irrigation management due to cost and regulatory issues. Unfortunately, our studies indicate that the EM sensors are not useful for irrigation management due to inaccuracy and variability. A new generation of EM sensors should be developed to overcome the problems of those currently available. In the meantime, tensiometers, electrical resistance sensors and soil probes may fill the gap for irrigation management based on soil water sensing. However, many farmers are successfully using irrigation scheduling based on crop water use estimates from weather station networks and reference ET calculations. When used in conjunction with direct field soil water observations to avoid over irrigation, the ET network approach has proved useful in maximizing yields.

INTRODUCTION

For most uses and calculations in irrigation management and research, soil water content (θ_v, m^3 m^{-3}) is expressed as a volume fraction,

$$\theta_v = \frac{\text{volume of soil water}}{\text{total volume of soil}} \qquad [1]$$

Volume per volume units are used in most calculations of soil water movement and crop water uptake, including those in irrigation scheduling computer programs or back-of-the-envelope checkbook type calculations. These units make it easy to convert water contents, θ_v, measured in a soil profile over a given depth, z, to an equivalent depth of water (θ_z) by multiplying the water content by the depth: $\theta_z = \theta_v$ z. The units of θ_z are the length units of z, typically mm, cm or inches. For example, the depth of irrigation water, I_{zUL}, that a uniform soil can accept without large losses to deep percolation is limited on the upper bound by the depth of the root zone, z_r, and the difference between the mean water content of the root zone, θ_r, and the water content at field capacity, θ_{FC}; that is, $I_{zUL} = z_r(\theta_{FC} - \theta_r)$. For soils that have differences in soil texture with depth, similar calculations can be done layer by layer using the different texture-specific field capacity values and water contents available from most soil surveys or computer programs (e.g., http://staffweb.wilkes.edu/brian.oram/soilwatr.htm)..

Soil texture is quantified by the relative percentages by mass of sand, silt, and clay after removal of salts and organic matter. Both texture and structure determine the soil-water characteristic curve, which quantifies the relationship between soil water content and soil water potential, which is the strength with which the soil holds water against removal by plants. This relationship differs largely according to texture (Fig. 1), but can be strongly affected by organic matter and salt contents. The range of plant-available water (PAW) possible for a given soil is determined by two limits. The upper limit, also know as the field capacity, is often defined as the soil water content of a previously saturated soil after 24 h of free drainage into the underlying soil. The field capacity can be viewed as the water content below which the soil does not drain more rapidly than the crop can take up water. In heavier textured (i.e., more clayey) soils, this limit is often characterized as the water content at −0.10 kPa soil water potential. In more sandy ("lighter") soils, the upper limit may be more appropriately placed at −0.33 kPa soil water potential. The difference in soil water potentials that are related to the upper limit of PAW is due to the relatively large conductivities for water flux in lighter soils near saturation, which means that lighter soils will drain more rapidly. The lower limit of PAW, also known as the permanent wilting point, is often defined as the soil water content at which the crop wilts and cannot recover if irrigated. The soil water potential associated with the lower limit varies with both the crop and the soil; but is often taken to be −1500 kPa. The amount of PAW differs greatly by soil texture. For example, as illustrated in Figure 1, a clay soil may have a plant available water content range of 0.19 to 0.33 m^3 m^{-3},

or 0.14 m^3 m^{-3} PAW; whereas a silt loam may have a larger PAW content range of 0.08 to 0.29 m^3 m^{-3}, or 0.21 m^3 m^{-3} PAW. Sandy soils tend to have small amounts of PAW, such as the 0.04 m^3 m^{-3} for the sandy loam illustrated in Fig. 1 or the 0.06 m^3 m^{-3} reported by Morgan et al. (2001a) for an agriculturally important fine sand in Florida. Thus, irrigation management often focuses on applying smaller amounts of water more frequently on sandy soils.
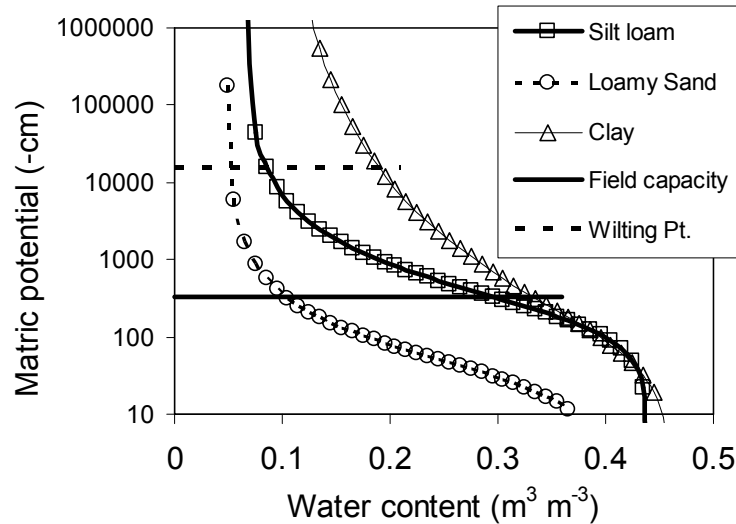

Figure 1. The soil water content vs. soil water matric potential relationship for three soil textures as predicted by the Rosetta pedotransfer model (Schaap et al., 2001). Horizontal lines are plotted for the field capacity, taken as −333 cm (~−33 kPa), and for the wilting point, taken as −15 000 cm (~−1500 kPa).

Crops differ in their ability to extract water from the soil, with some crops not capable of extracting water to even −1500 kPa, and others able to extract more water, reaching potentials even more negative than -1500 kPa (Ratliff et al., 1983, Tolk, 2003) (Fig. 2). Confounding this issue is the soil type effect on rooting density and on the soil hydraulic conductivity, both of which influence the lower limit of PAW for a particular crop. The fact that soil properties vary with depth means that the lower limit of PAW may be best determined from field, rather than laboratory, measurements.

The available soil water holding capacity (AWHC) is a term used to describe the amount of water in the entire soil profile that is available to the crop. Because water in the soil below the depth of rooting is only slowly available, the AWHC is generally taken as the sum of water available in all horizons in the rooting zone, calculated for each horizon as the product of the horizon depth and the PAW for that horizon. For example, for a crop rooted in the A and B horizons of a soil the AWHC is the product of the PAW of the A horizon times its depth plus the PAW of the B horizon times the rooted depth in the B horizon (Table 1).
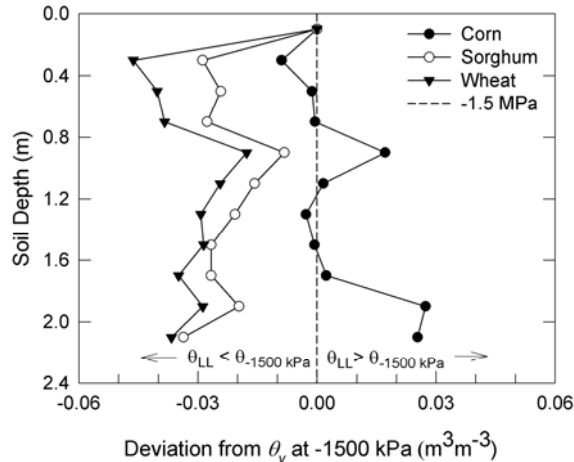
Figure 2. Deviation of the lower limit of water extraction, θ_{LL}, measured in the field using a neutron probe, from that measured at −1500 kPa in the laboratory on soil cores taken at several depths in the soil. Data are for corn, sorghum and wheat crops grown in a Ulysses silt loam (Tolk, 2003).

Table 1. Example calculation of available water holding capacity (AWHC) in the rooting zone of a crop rooted to 0.95-m depth in a soil's A and B horizons, each with a different value of plant available water (PAW).

Horizon	Depth range (cm)	Rooting depth (cm)	Rooted depth (cm)		PAW ($m^3\ m^{-3}$)		AWHC (cm)
A, silt loam	0 to 20	0 to 20	20	×	0.21	=	4.2
B, clay	20 to 100	20 to 95	75	×	0.14	=	10.5
						Sum	14.7

For irrigation scheduling using the management allowed depletion (MAD) concept (Fig. 3), irrigation is initiated when soil water has decreased to the θ_{MAD} level. The θ_{MAD} value may be chosen such that the soil never becomes dry enough to limit plant growth and yield, or it may be a smaller value that allows some plant stress to develop. Choice of the θ_{MAD} value needs to consider the irrigation capacity (flow rate per unit land area), which determines how quickly a given irrigation amount can be applied to a specified sized field. It is common to irrigate at some value of water content, θ_{MAD+}, that is larger than θ_{MAD}. This is done to ensure that the error in water content measurement, which may cause inadvertent over estimation of water content, is not likely to cause irrigation to be delayed until after water content is actually smaller than θ_{MAD}. Minimizing the difference, $d = \theta_{MAD+} - \theta_{MAD}$, allows the irrigation interval to be increased. It is desirable to know the number of samples required to estimate the water content to within d of θ_{MAD} at the $(1 − \alpha)$ probability level. Knowing the sample standard deviation, S, of soil water content measurements, the required number of samples, n, can be estimated as

$$n = \left(\frac{u_{\alpha/2} S}{d} \right)^2 \qquad [2]$$

where $u_{\alpha/2}$ is the $(\alpha/2)$ value of the standard normal distribution, and $(1 - \alpha)$ is the probability level desired (eg. 0.95 or 0.90). Equation [2] is valid for normally distributed values that are independent of one another and for the population standard deviation estimated from the sample standard deviation, S, of a large number of samples.
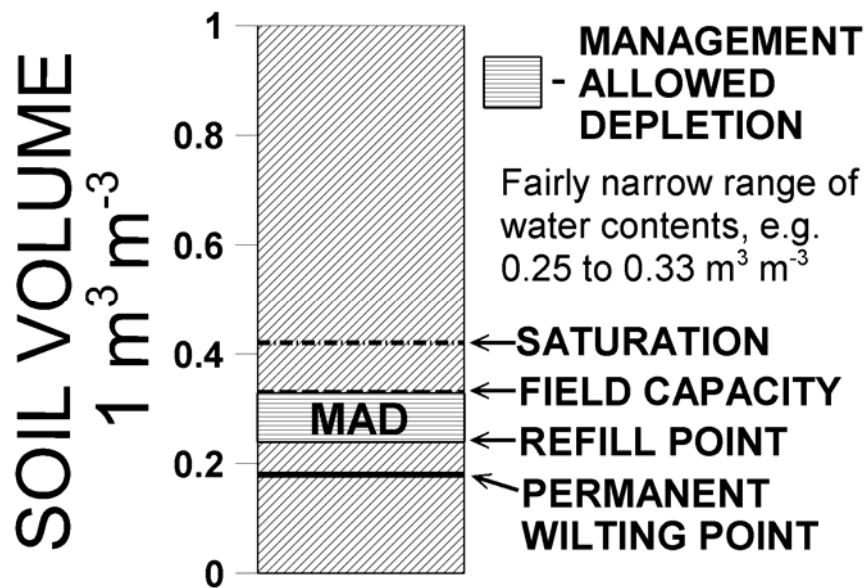

Figure 3. Illustration of the soil profile indicating fractions of the total soil volume (here represented by unity) that are occupied by water at four key levels of soil water content. For this silty clay loam, the soil is full of water at saturation (0.42 m^3 m^{-3}), drains easily to field capacity (0.33 m^3 m^{-3}), and reaches the permanent wilting point (15 bars) at 0.18 m^3 m^{-3} water content. To avoid stress in a crop such as corn, irrigations are scheduled when the soil water content reaches or is projected to reach 0.25 m^3 m^{-3}, the value of θ_{MAD} for this soil and crop.

Because this analysis depends on the sample standard deviation determined by repeated readings with a particular device, it encapsulates the variability of readings from that device; but it does not include bias (non-random error) that may be present in the device readings due to, for example, inaccurate calibration. Aside from large-scale spatial variability, the calibration is a potentially large source of error; and this error is not reduced by repeated sampling (Vauclin et al., 1984). Thus, careful field calibration is essential to minimize such bias (Hignett and Evett, 2002; Greacen, 1981). In most cases, this analysis may be applied to values of soil profile water storage that are calculated on the basis of samples at multiple depths.

For example using the data for the three soils in Fig. 1, the differences between the values of water content at field capacity, θ_{FC}, and at the permanent wilting point, θ_{PWP}, are the plant available water, θ_{PAW} (Table 2). Assuming that the management allowed depletion is 0.6 of θ_{PAW}, the allowable ranges of water content during irrigation scheduling are 0.126, 0.085, and 0.022 $m^3\ m^{-3}$ for silt loam, clay, and loamy sand, respectively (Table 2). These narrow ranges place high accuracy demands on soil water sensing equipment. Assuming that soil-specific calibrations have been performed to minimize bias, and that the accuracy of calibration is an acceptably small value (as determined by the RMSE of regression << MAD range), a specific sensor must still provide an acceptably precise mean value of field readings (that is, standard deviation of readings at multiple locations < MAD range).

Table 2. Example calculation of management allowed depletion (MAD, $m^3\ m^{-3}$) in three soils with widely different textures. The small range of MAD severely tests the abilities of most soil water sensors, particularly for the loamy sand soil.

Horizon	θ_{FC} ($m^3\ m^{-3}$)	θ_{PWP} ($m^3\ m^{-3}$)	θ_{PAW} ($m^3\ m^{-3}$)		MAD fraction		MAD ($m^3\ m^{-3}$)
silt loam	0.086	0.295	0.209	×	0.6	=	0.126
loamy sand	0.066	0.103	0.037	×	0.6	=	0.022
clay	0.190	0.332	0.142	×	0.6	=	0.085

The ability to provide an acceptably precise mean value of field readings using a cost-effective number of access tubes or sensors in the soil is where some sensors are lacking (Table 3). In particular, the capacitance sensors appear to be very sensitive to small-scale variations in soil water content, and thus require many more access tubes to attain a precision equal to that attained with much fewer NMM or gravimetric samples. Another example is data from Australia showing that the standard deviation of profile water contents reported by the EnviroSCAN system was 12.36 cm compared with S of 0.93 cm for the NMM in the same flood irrigation basin (Evett et al., 2002b).

If no other information were available about soil water variability, sampling a field for profile water content would typically require many profiles to be sampled, either directly or using water content sensor(s) in access tubes. However, distribution of profile water content tends to be temporally stable in some fields, at least over a growing season (Vachaud et al., 1985; Villagra et al., 1995). This means that there are locations in the field where the profile water content is usually very representative of the mean for the field, or of the extremes (Fig. 4) (Evett, 1989). Irrigators recognize this when they observe the crop in a field for water stress or when they probe the soil for water content. For example, an irrigator may ignore drier crops at the edge of a field, or a low, wet corner of the field when assessing the need to irrigate. The tendency is to make observations in places that show the mean behavior of the field. This is not an adequate way of choosing observation locations for a scientific experiment for which blocking,

randomization, replication and other considerations are required for statistical validity. But, for irrigation management in production agriculture, the choosing of measurement locations on the basis of observed soil and plant properties that are representative of the field may be the most cost effective and efficient method.

Table 3. Calculation using Eq. [2] of the number of access tubes (N) needed to find the mean profile water storage in a field to a precision d (cm) at the (1 - α) probability level ($\mu_{\alpha/2}$ is the value of the standard normal distribution at α/2) for a given field-measured standard deviation (S, cm) of profile storage. Data are from ten access tubes for each device, spaced at 10-m intervals in transects that were 5-m apart.

Method	Soil condition	S (cm)	N	N
		α =	0.05	0.10
		$\mu_{\alpha/2}$ =	1.96	1.64
		d (cm) =	1	0.1
Diviner 2000†	Irrigated	1.31	6.6	464
	Dryland	2.42	22.5	1584
EnviroSCAN†	Irrigated	1.52	8.9	625
	Dryland	2.66	27.2	1914
Delta-T PR1/6†	Irrigated	2.72	28.4	2002
	Dryland	12.16	568.0	40006
Sentry 200AP†‡	Overall	3.78	54.9	3866
Trime T3	Irrigated	0.75	2.2	152
	Dryland	2.38	21.8	1533
Gravimetric by push tube	Irrigated	0.45	0.8	55
	Dryland	0.70	1.9	133
CPN 503DR NMM	Irrigated	0.15	0.1	6
	Dryland	0.27	0.3	20

† Capacitance type sensors
‡ Estimated from data of Evett and Steiner (1995)

The previous paragraph not withstanding, the scheduling of irrigations on the basis of a single profile water content measurement in a field is prone to large errors. Also, there is strong evidence that actively growing vegetation can reduce or eliminate the temporal stability of water content, particularly in the root zone (Hupet and Vanclooster, 2002) and in fields with little topographic relief. A reasonable minimum for the NMM or gravimetric sampling is three to four profile water content measurements at locations chosen to be representative of the field (Tollner et al., 1991). For other methods, such as the capacitance sensors, that sense smaller volumes resulting in larger values of S, the number of profile measurements needed may be much greater (Table 3).
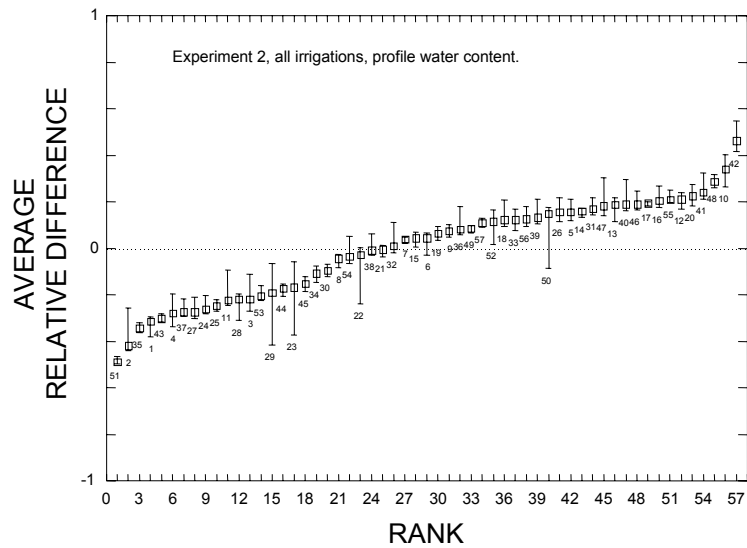
Figure 4. Ranking of locations by their average relative difference from the field mean profile water content. Vertical bars indicate the range of values observed over the course of the experiment. Location 21 in particular was close to the mean profile water content at all times.

TWO FIELD STUDIES

Electromagnetic (EM) soil water sensing systems are rapidly entering the soil water sensor market. Common systems use sensors based on capacitance or time domain reflectometry (TDR) principles. For three capacitance soil water sensing systems (Sentek EnviroSCAN[1], Sentek Diviner 2000, and Delta-T PR1/6), the Trime T3 quasi-TDR soil water sensing system, and the neutron moisture meter (NMM), we developed soil-specific calibrations for the A, Bt, and calcic Bt horizons of the Pullman soil at Bushland, TX (Evett et al., 2006). We applied these calibrations to data acquired in a wheat field in 2003 in order to investigate the variability of soil water estimates without the confounding factor of inaccurate factory calibrations. There were ten access tubes for each system, arranged in linear transects. After the first three measurement cycles, half of the winter wheat field (containing five access tubes) was irrigated to see how the five systems were able to sense the differences in water content. Access tubes were spaced 10-m apart. In addition to the five soil water sensing methods, gravimetric samples were taken with an hydraulic push probe (Giddings) in transects on some of the sampling dates. Sampling points were spaced 10-m apart; and samples were 10-cm in height and had a volume of 75.5 cm^3. The data in Table 3 are from this study.

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[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

Profile water contents reported by the six methods differed considerably (Figure 5), particularly in the degree of water content variability and the shape of the profile, which is influenced by over and under estimation of water content at different depths. The smallest variability of water content was reported by the NMM; and the NMM data matched the direct gravimetric data better than any other sensor. Variability of gravimetric measurements was only slightly larger than that of the NMM; and variability of Trime T3 results was somewhat more variable, but still representative of the profile water content in much the same way as the NMM. In this field, the depth to the $CaCO_3$-enriched (caliche) layer was ~120 cm. As shown by the NMM and gravimetric results, inherent soil water variability was larger in the caliche horizon below 120 cm than in the Bt and A horizons above 120 cm. The larger variability below 120 cm is due to the presence of prairie dog burrows that are present in the softer caliche soil (Fig. 5, right). These are invariably found in soil pits dug at the Bushland research station. The burrows contain soil that has washed in from the overlying Bt and A horizons; and they typically exhibit smaller bulk density than the overlying and surrounding soil. Depending on the presence or absence of macropore flow, typically occurring in soil cracks in the overlying A and Bt horizons of this soil, the soil in burrows may exhibit larger or smaller water content than surrounding soil.

While all of the EM sensors exhibited more variability than the NMM, the three capacitance sensors exhibited the most variability as well as a tendency to severely underestimate water content in the A horizon above 50-cm depth. This could be indicative of a weakness in the soil-specific calibrations of Evett et al. (2006), or it might be due to poor contact of the plastic access tubes in this soil after more than seven months in the soil. Particularly near the top of the access tubes, vibration from repeated instrument insertion and extraction can cause small annular air spaces to develop between the soil and access tube. Also, shrinkage and swelling of the soil could create air space around the tubes near the surface where the soil is unconstrained. The NMM is not sensitive to such small air gaps, but they can permit water movement down the outside tube walls. The under estimation by the capacitance sensors was so consistent that we think it is due to a very strong dependency of the calibration equation coefficients on clay content of the soil, which increases strongly with depth in this soil. The variability in water contents illustrated in Fig. 5 is reflected in the values of S in Table 3.

A second study was done in a drip irrigated sweet pepper field near Five Points, CA, in the San Joaquin Valley on a Panoche clay loam soil in 2005. Data are presented for two periods in the season (Fig. 6). The first period was during the irrigation season as pepper fruits were developing; and the second period was during field dry down after irrigation had been suspended, but the crop was still transpiring. Sensors studied were the NMM, and three capacitance sensors: the Delta-T PR2/6 (successor to the PR1/6), the Sentek Diviner 2000 and the Sentek

EnviroSCAN. Data from the NMM showed that, below the surface, the soil water content profile was nearly uniform with depth at both dates, though the decrease in water content during dry down was evident. Gravimetric data (not shown) from the same field showed the same uniformity of water content with depth as did the NMM. Data from the PR2/6 indicated that the water content was much more variable, and that water content increased with depth during the dry down period. Neither indication is true. What is true is that this soil becomes increasingly saline during the irrigation season, and that salinity increases with depth in the profile at the end of the season. Thus, the increasing water contents with depth from the PR2/6 are the result of this sensor being sensitive to salinity, not an indication that water content increased with depth. Data shown are using the factory calibration for clay soils for the PR2/6, which resulted in both over and under estimation of water contents, depending on the depth. Data for the EnviroSCAN and Diviner 2000 for the same two periods are similar. They show more variability than actually existed at the scale of crop water uptake; and similar to the PR2/6, they showed a false increase of water content with depth late in the season, probably due to salinity increasing with depth. Again, the use of factory calibrations resulted in some large over and under estimations of water content.
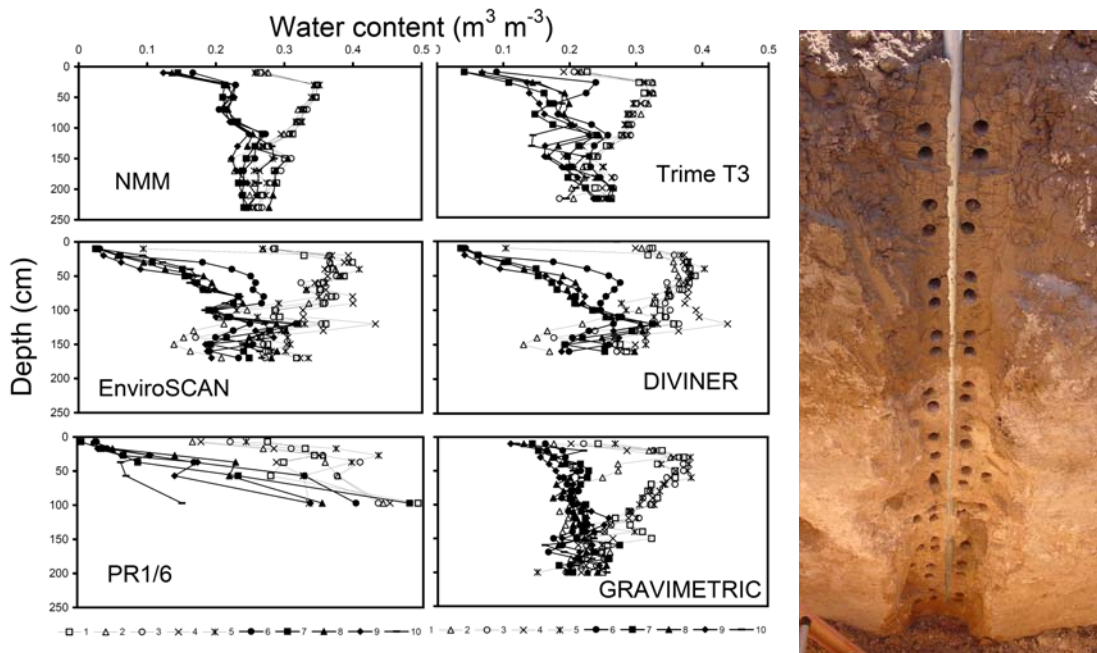

Figure 5. (Left) Profile water contents for ten transect locations for each of five sensor systems, in a winter wheat field on 5 November, 2003, compared with gravimetric measurements. Half of the field (five transect locations) was irrigated. Sensing methods were frequency domain (EnviroSCAN, Diviner 2000, and PR1/6), quasi-TDR (Trime T3), and the neutron moisture meter (NMM). (Right) Photograph of the Pullman soil profile to 2-m depth showing the lighter colored caliche horizon.
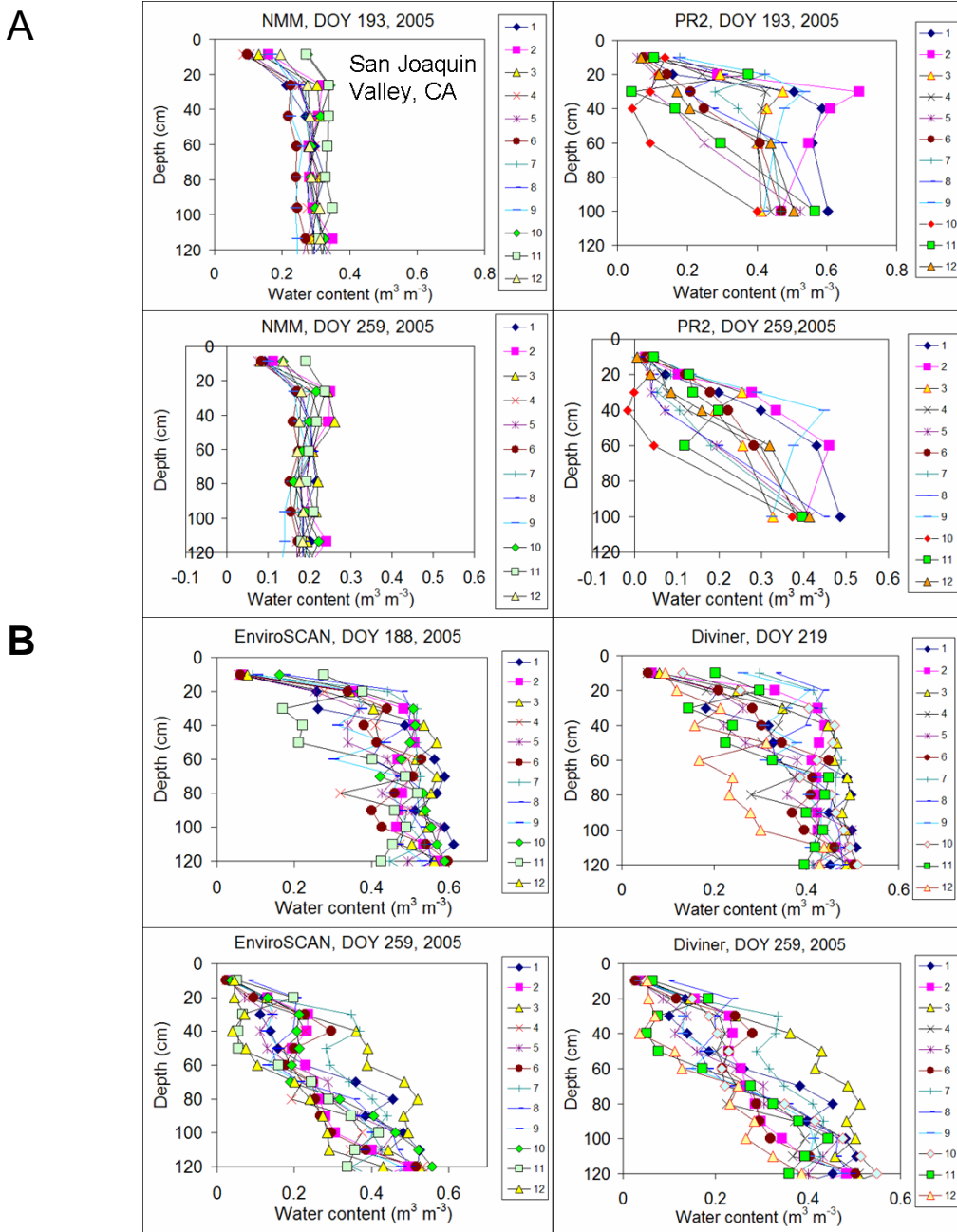
Figure 6. Water content data from two periods for each sensor during a 2005 study in California. The first period was during the irrigation season as pepper fruits were developing; and the second period was during field dry down after irrigation had been suspended, but the crop was still transpiring. Sensors studied were the NMM and the Delta-T PR2/6 (shown in A), and the Sentek Diviner 2000 and EnviroSCAN (B).

EFFECT OF SALINITY

World wide, 20% of irrigated soils are salt affected (Hachicha and Abd El-Gawed, 2003). Sensitivity to soil salinity, measured as the bulk electrical conductivity (BEC), limits the applicability of frequency domain or power loss sensors in many irrigated soils in which BEC varies across the field (Fig. 7) and with time (Fig 8). Variations of BEC of as much as 12 dS m^{-1} can occur over distances of less than one meter (Burt et al., 2003), and differences equally as large can occur from year to year or even within an irrigation season in one location (Hanson et al., 2003). Abdel gawad et al. (2003) measured periodic soil solution EC variations of 5 to 6 dS m^{-1} under drip irrigation in Syria. Mmolawa and Or (2000) measured a BEC change from 0.3 to 2.3 dS m^{-1} in a few hours under drip irrigation of corn. While it is possible to calibrate most sensors for a particular BEC, in these situations of temporally and spatially variable BEC, such a calibration is not applicable. From the available data, it is clear that errors larger than 50% in soil water content at a single location, and errors similarly large in soil profile water content are possible given the range of BEC values measured. Spatial and temporal variations of BEC are not confined to drip irrigation, but are present under furrow, flood, and sprinkler irrigation as well.
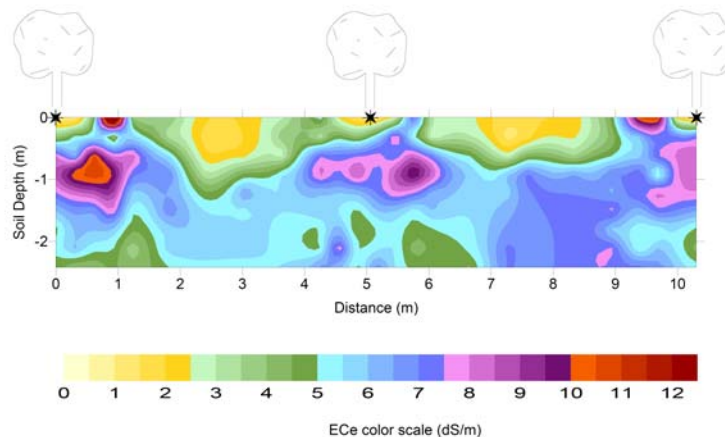

Figure 7. Variations in EC of saturation paste soil extracts (EC$_e$) in two dimensions of a pistachio plantation that was drip irrigated in California. (Burt et al., 2003)
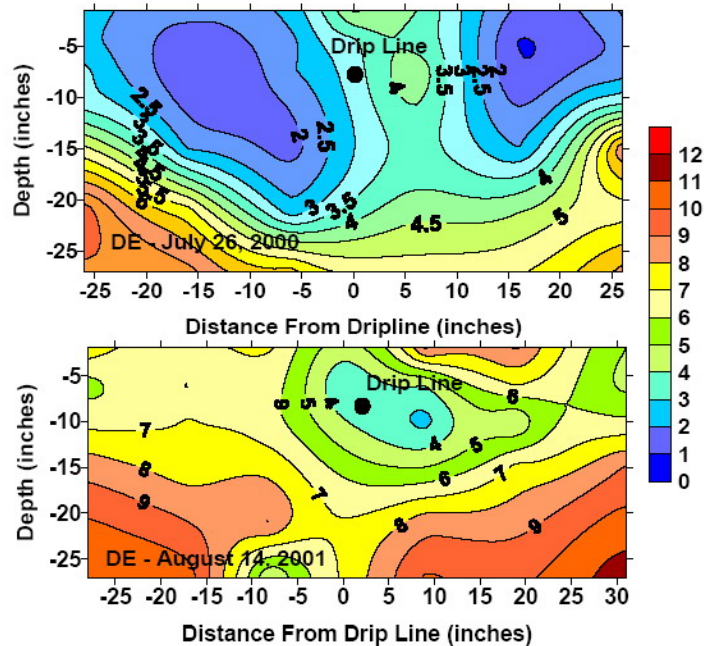
Figure 8. Variations in EC from saturation paste soil extracts from a single location in a drip-irrigated tomato field in California in two different years. No yield variation was found. (Hanson et al., 2003)

Sensors based on electromagnetic principles are often also sensitive to clay content and type even in non-saline soils. This is because clays exhibit varying degrees of charge and are associated with cations or anions in the soil solution to varying degrees. Commonly, clays exhibit negative charge and are associated with cations to a degree that is evaluated as the cation exchange capacity (CEC). As the soil content of high CEC clay increases, the soil becomes more electrically lossy, that is, more capable of affecting the movement of electrical fields. This affects the frequency of oscillation of capacitance systems and the power loss of power loss systems in a way that is separate from, but not completely independent of, the soil water content. Examples include the much different calibration equations developed for the several soils existing under one center pivot irrigation system in France (Fig. 9) (Ruelle et al., 2003, personal communication), and the different calibration equations reported by Baumhardt et al. (2000) at Lubbock, TX, and Morgan et al. (1999) for the Sentek EnviroSCAN system.
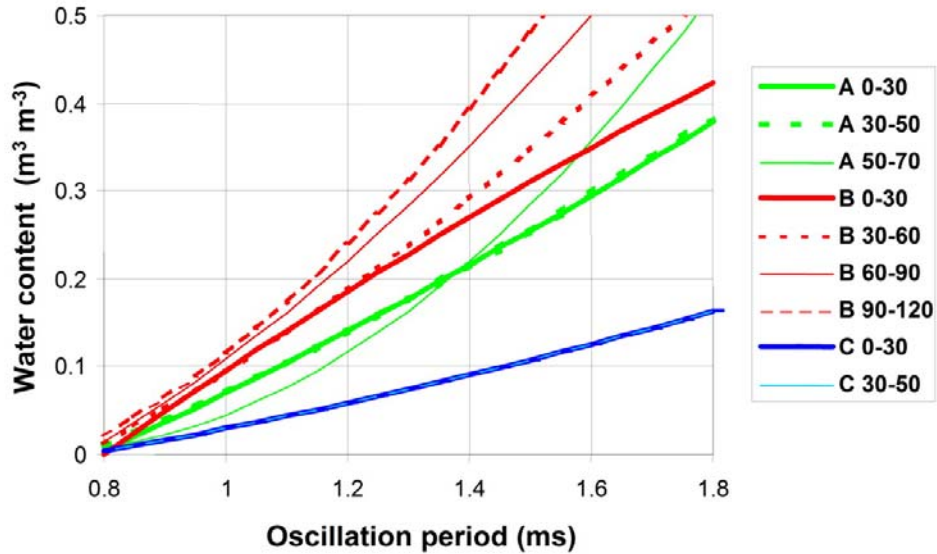
Figure 9. Calibrations of the model CS615 soil water probe from Campbell Scientific, Inc. in nine different soil layers of three different soils (A, B, and C), illustrating the wide variance in calibration equations for different layers in a particular soil and among soils (Ruelle et al., 2003, personal communication).

GRANULAR MATRIX SENSORS

Several types of granular matrix sensors (GMS) are on the market. The sensor consists of a porous medium in which are embedded two wires, often connected to wire mesh electrodes inside the sensor. The reading is of the electrical resistance in the medium between the wires or mesh electrodes. Often, a quantity of gypsum (calcium sulfate) is included to buffer the soil water solution and decrease effects of salinity on the resistance. The greater the soil water tension, the less water is in the porous medium, and the greater the electrical resistance. Calibration may be done in a porous medium covering a pressure plate, which is subjected to several values of pressure in a pressure chamber. Calibrations are soil specific, so it is wise to use the soil to be measured as the porous medium. Installation and contact problems are similar to those for a tensiometer or gypsum block, including contact problems in coarse sands and shrink/swell clays. At tensions less than 30 kPa, Taber et al. (2002) found that tensiometers responded more rapidly than GMS sensors in silt loam, loam, and coarse sand. As with gypsum blocks, reading requires an alternating current to minimize effects of capacitive charge build up and ionization. Lack of precision and calibration drift over time may limit use of GMS for determining soil water potential gradients.

The useful range of readings is approximately −10 to −200 kPa matric potential, though Morgan et al. (2001b) were able to use GMS sensors to −5 kPa in a fine sand. Sensors may be manually read or data logged (resistance reading). Some

hysteresis is noted with these sensors; and they are temperature sensitive (as much as 20 kPa per 10°C, Shock, 2003). Like gypsum blocks, GMS may be installed to practically any useful depth, limited only by wire length. Fewer problems with soil contact are noted with GMS. The usefulness of GMS systems for irrigation scheduling has been illustrated by work done with onions, potato (Fig. 10), alfalfa, and sugar beet in the Malheur Valley of Oregon (Shock, 2003; Shock et al., 2003). Because of soil and irrigation variability, at least six sensors should be used to provide data for irrigation scheduling (Shock, 2003). For irrigation science, the GMS can be useful if calibrated for the soil over a range of temperatures and soil water potentials, and if soil temperature is measured at the location of each sensor so that calibration corrections for temperature can be applied. Automatic irrigation scheduling has been successfully implemented using GMS for high-value row crops (Shock et al., 2002) and for landscapes (Qualls et al., 2001).
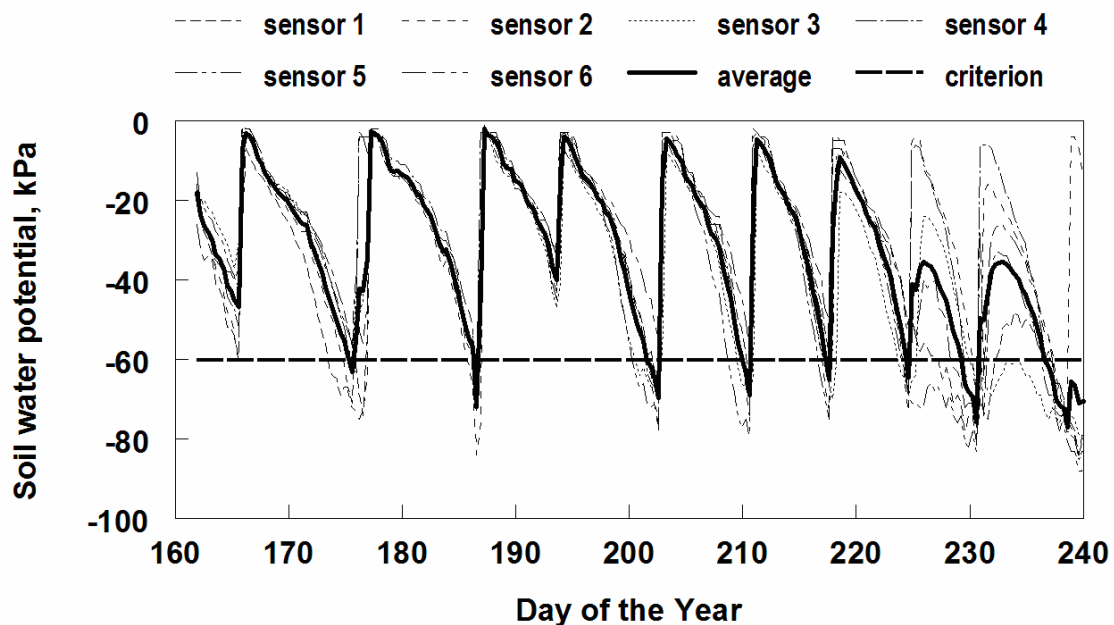

Figure 10. Soil water potential in a sprinkler-irrigated potato field as sensed with six granular matrix sensors datalogged using a Hansen model AM400 data logger, showing very good control of soil water potential. Note the dry-down period at the end of the irrigation season (Shock et al., 2003)

DIRECT OBSERVATION

Direct observations can be very useful in guiding irrigation management. The soil feel and appearance method involves squeezing a ball of soil in the hand and comparing its feel and appearance to photographs that show the appearance of different soil textures at various water contents. The USDA-NRCS publishes a handy guide with the photographs and descriptions of how the soil feels in the

hand at different water contents. While it is an approximate guide, this method is fairly simple, and when used by an experienced irrigator can give the amount to irrigate. It does require a trip to field, during which the leaf and crop appearance can also be assessed (curl, color, wilting). Usually, these are apparent only after stress is enough to limit yield. The feel and appearance guide can be found at http://www.mt.nrcs.usda.gov/technical/ecs/agronomy/soilmoisture/index.html.

Another method of direct observation common in irrigated Great Plains soils is the push probe (Fig. 11). The probe consists of a 3/8 or ½-inch diameter steel rod with a T handle at the top and a ball bearing of slightly larger diameter welded to the bottom end. The ball bearing makes a hole larger than the diameter of the rod so that most of the resistance to penetration into the soil is at the ball, not due to friction between the soil and the rod. An experienced irrigator can fairly quickly assess variability in irrigation infiltration depth across a field, and perhaps most importantly can identify deep wetting of the profile that can result in deep percolation losses. Water lost to deep percolation carries with it costly fertilizers, the loss of which can reduce yield appreciably. Indeed, among farmers who have been over irrigating in the past, it is a common observation that reduction in water application is accompanied by increase in yield.

Direct Observation Methods

T handle of same material

- Push-probe, shovel insertion, etc.
  – Fairly accurate for depth of wetting front – important for assessing irrigation uniformity
  – Inaccurate for water content, but useful in experienced hands
  – Push probe allows quick evaluation of irrigation uniformity over the field

1.5 m

Approx. 10 mm steel rod →

Approx. 12 mm ball bearing welded to end →

Figure 11. The push probe, a useful device for assessing irrigation penetration depth and relative water content.

CONCLUSIONS

The relatively expensive and high tech capacitance and other electromagnetic (EM) sensors are too inaccurate to be useful for assessing when and how much water to apply through irrigation. Sensitivities to soil bulk electrical conductivity, whether derived from clay type and content or from salt content, are too great with the current crop of EM sensors. A new generation of EM sensors should be developed to overcome the problems of those currently available. The neutron moisture meter, even though posing negligible health hazard, faces stiff regulation and is useful mostly for research. Granular matrix sensors (resistance blocks) are useful in some soils and are particularly justified when produce quality is a concern. Direct observation remains the most used method of irrigation scheduling. Although not addressed in this paper, producers who can take advantage of a weather station network that provides crop water use estimates based on reference evapotranspiration are successfully using those networks to schedule irrigations. When used in conjunction with direct observations (e.g. push probes) to avoid over irrigation, the ET network approach has proved useful in maximizing yields. One example is the Texas High Plains ET Network (http://txhighplainset.tamu.edu/) (Howell, 1998; Howell et al., 1998; Marek et al., 1998). For a more in-depth and technical discussion of soil water properties and soil water sensing systems, see Evett (2007).

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