NebGuide
University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources

G2245

Corn Soil-Water Extraction and Effective Rooting Depth in a Silt-Loam Soil

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This UNL Extension NebGuide addresses crop soil-water extraction amounts and patterns, with an emphasis on corn, and discusses how these patterns can be impacted by soil properties, irrigation management practices, and other factors. In addition, the concept of effective rooting depth is addressed and explained in the context of irrigation and nutrient management for corn grown in a silt-loam soil.

Soil-Water Extraction

Soil-water extraction is the amount of water removed from an individual soil layer as a result of root water uptake in the soil profile and/or soil evaporation (E) at the soil surface. Therefore, total soil water extraction (i.e., the sum of soil water extraction for all soil depths) in the effective crop root zone is assumed to be equivalent to actual crop evapotranspiration (ETa). In some cases, soil-water extraction is also referred to as soil-water depletion by the crop. In most cases, soil-water extraction by crop roots is not uniformly distributed in the soil profile and varies spatially and temporally. Under non-stressed water and nutrient conditions and if root development is not impeded by a restrictive soil layer or other factors, soil-water extraction typically follows a conical water uptake pattern of 40 percent, 30 percent, 20 percent, and 10 percent of total water uptake from the first, second, third, and last one-fourth of total plant-rooting depth. An illustration and brief description of the conical water uptake pattern is presented in the UNL Extension NebGuide *Irrigation Management for Corn (G1850)*.

Soil-water extraction patterns can be used to determine effective rooting depth, proper nutrient application amount and timing, magnitude and frequency of irrigation applications, and proper placement depth and/or spacing of subsurface or surface drip irrigation systems and soil water measurement equipment. Root-zone extraction patterns also provide crop water-stress information to better time irrigation applications based on crop growth stages. Based on these soil-water extraction patterns, proper deficit irrigation strategies can be developed to achieve optimum crop yield and water use efficiency under various water allocations.

Impacts on Soil-Water Extraction

Trends and magnitudes of soil-water extraction depend on crop type and phenological development as well as external factors imposed on the crop's physiological functions, including

- planting population density;
- soil physical and chemical properties;
- water, nutrient, and land management practices;
- irrigation method and management, including irrigation frequency; and
- microclimatic conditions, especially seasonal precipitation distribution and amount.

These external forces can alter the typical conical water uptake pattern. For example, *Figure 1A* illustrates how soil layering can reduce soil water extraction (root water uptake) of a corn cropping system in the second foot as compared to the third foot. The data presented in *Figure 1A* was collected at the University of Nebraska–Lincoln Institute of Agriculture and Natural Resources, South Central Agricultural Laboratory (SCAL), near Clay Center, Nebraska, in 2011. At SCAL an argillic horizon (i.e., clay layer) exists in the second foot soil layer, but can extend to the third foot, which can limit plant available water (PAW). Plant available water is the amount of water in the soil profile that is freely available to the crop and can be calculated as the difference between the current soil moisture and soil moisture at permanent wilting point (PWP). A clay layer can have lower PAW than the remaining soil profile in a silt-loam soil, since clay particles hold or bind soil moisture at greater tensions than silt and sand particles. Consequently, even if the clay layer has greater soil water-holding capacity, it is possible less energy is required by the crop to extract water from lower soil depths than the clay layer itself. Soil water potential is a measure of the amount of energy required by the crop to extract water from the soil. The UNL Extension Circular

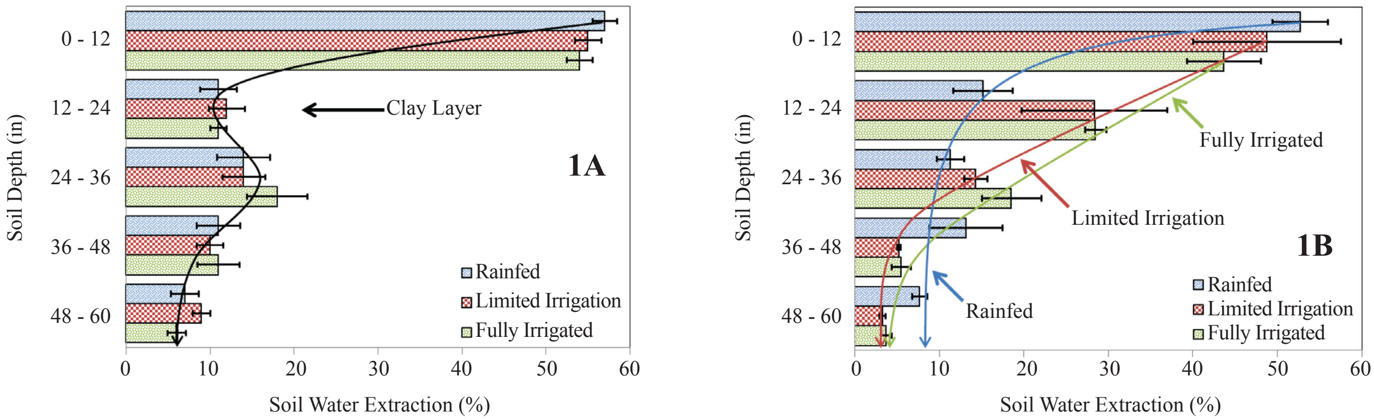

Figure 1. Average soil-water extraction percentages [and standard deviations (horizontal bars)] of a corn cropping system in a silt-loam soil for individual soil depths (12-inch increments) under full irrigation, limited irrigation (75 percent of full irrigation), and rainfed conditions at the University of Nebraska–Lincoln South Central Agricultural Laboratory (SCAL) near Clay Center, Nebraska in 2011 (A) and 2012 (B).

Principles and Operational Characteristics of Watermark Granular Matrix Sensor to Measure Soil Water Status and its Practical Applications for Irrigation Management in Various Soil Textures (EC783) addresses soil water potential sensors and their use for irrigation management. Soil moisture sensors that do not estimate soil water potential, but rather volumetric water content [e.g., capacitance or time domain reflectometry (TDR)], should be accompanied by knowledge of soil hydraulic properties (e.g., PWP) to determine differences in PAW across soil layers. Soil hydraulic parameters are reported for most soil series by the Natural Resources Conservation Service Web Soil Survey (*http://websoilsurvey.nrcs.usda.gov*).

Irrigation management also can impact the magnitude and trend of soil-water extraction. For example, fully irrigated corn (i.e., irrigations are managed to prevent any crop water stress) at SCAL resulted in a lower percentage of soil-water extraction in the top one foot and greater extraction in the third foot as compared to limited irrigation (i.e., moderate crop water stress) and rainfed management strategies in 2011 and 2012 (*Figures 1A* and *1B*, respectively). However, different soil-water extraction patterns were observed for the same irrigation management protocol between years, primarily due to differences in climatic conditions. In 2011, frequent rainfall events occurred, which allowed for greater soil-water extraction near the soil surface compared to 2012 when conditions were drier, which promoted greater extraction below the first foot. Furthermore, it was observed that the clay layer had less impact on soil-water extraction in 2012, due to the clay layer thickness and depth changing between the 2011 and 2012 treatment locations within the experimental field. This illustrates that field scale variability in soil-water extraction patterns exist and may need to be accounted for when managing irrigation and nutrients. Irrigation methods also can impact soil-water extraction. For instance, for subsurface drip irrigation, greater soil-water extraction usually occurs near the drip lines.

Although irrigation methods and management can impact soil-water extraction, irrigation typically reduces inter-annual variability in soil-water extraction amount and pattern as compared to rainfed settings. Rainfed agriculture is subjected to rainfall amounts and non-uniform distributions and uptake throughout the crop growing season. As shown in *Table I*, soil-water extraction patterns were similar between rainfed and irrigated settings in 2011; whereas, extreme dry conditions in 2012 resulted in deep rooting and consequently, greater soil-water extraction in lower soil layers under rainfed conditions as compared to irrigated settings. Consistent irrigation scheduling will reduce year-to-year variability in crop growth and consequently, soil-water extraction patterns, which can aid in more effective water and nutrient management.

Other researchers have reported between 40 percent and 55 percent of total soil-water extraction occurring in the top one foot soil profile for various crops including corn, soybean, winter wheat, and sorghum. Under water-stressed conditions, it has been found that greater soil-water extraction can occur in deeper soil layers. However, different crop species have different root growth patterns and consequently, have different levels of tolerance to water stress. For example, sorghum has been reported to be more tolerant to water deficit than corn and soybean, due to a denser and more prolific root system. Other researchers have observed greater soil-water extraction in deeper soil layers at high nitrogen (N) fertilizer rates as compared to low or zero N fertilizer rates for both corn and wheat. In addition, tillage and residue management practices have been found to impact surface evaporation, which affects the water available for root uptake near the surface, and in turn influences soil-water extraction patterns.

Table I. Percent of seasonal total soil-water extraction (inches) for every 12 inches under full irrigation (i.e., non-water stressed), limited irrigation (i.e., moderate water stress), and rainfed settings at the University of Nebraska–Lincoln South Central Agricultural Laboratory (SCAL), near Clay Center, Nebraska in 2011 and 2012. Values correspond to *Figure 1*.

Year	*Irrigation Management*	*Soil Depth (inches)*				
		0 - 12	*12 - 24*	*24 - 36*	*36 - 48*	*48 - 60*
2011	Rainfed	57	11	14	11	7
	Limited	55	12	14	10	9
	Full	54	11	18	11	6
2012	Rainfed	53	15	11	13	8
	Limited	49	28	14	5	3
	Full	44	29	19	6	4

Effective Rooting Depth

Total and effective rooting depths for various crops at mature growth stage are presented in *Table II*. It should be noted that both total and effective rooting depths can be impacted by pH, restrictive or compacted soil layers, plant species, shallow water table depth, and other factors. Effective rooting depth is the active crop root zone where the majority (i.e., more than 80-90 percent) of soil-water extraction and nutrient uptake occurs and therefore, is commonly used to determine PAW and consequently, schedule irrigation. In addition, it is commonly used to determine the depth of soil samples for nutrient analysis. For example, the UNL Extension Circular *Fertilizer Suggestions for Corn (EC117)* recommends that soil samples be collected to a depth of 3 to 4 feet to estimate and account for nitrate-N (NO_3-N) remaining in the soil from the previous year.

Table II. Total and effective rooting depths (RD) for various crops, at mature growth stage, under well drained, deep silt-loam soils.

Crop Type	*Total Rooting Depth (feet)*	*Effective Rooting Depth (feet)*
Alfalfa	8 - 12	4 - 5
Corn	5 - 6	3 - 4
Sorghum	6 - 7	3 - 4
Soybean	5 - 6	2 - 3
Winter Wheat	4 - 5	2 - 3

Effective rooting depth is not constant, but changes throughout the growing season. After planting, the root system is concentrated near the soil surface. As the crop develops, effective rooting depth increases until the crop reaches full vegetative growth (e.g., at or near silking for corn). Some researchers note that effective rooting depth is 50 percent of total rooting depth; however, early in the growing season when the root zone is shallow, a greater percentage (e.g., 75 percent to 100 percent) should be used. After vegetative growth is complete, effective rooting depth is usually held constant through the reproductive period, but can be increased late in the growing season to further deplete available soil-water. Effective rooting depth is usually decreased at the end of the season during less sensitive growth stages (e.g., end of dent stage for corn), when water requirements have decreased and the final irrigation of the season is being scheduled. See the UNL NebGuide *Predicting the Last Irrigation of the Season* (G1871).

History of soil-water extraction patterns can be used to determine effective rooting depth. As an example, *Figure 2* shows cumulative soil water extraction for a corn cropping system not under water or nutrient stress at SCAL in 2012. The extraction trends illustrate that early in the growing season the majority of soil-water extraction occurred in the first foot and not until the corn reached silking (R1 growth stage) did the crop begin to extract considerable water from the second and third foot. Through the reproductive growth period [silking to physiological maturity (R6)] more than 90 percent of the total extraction occurred in the top three feet. Average soil-water extraction amounts for every 12-inch soil depth for different corn growth stages and days after planting (DAP) are presented in *Table III*. To prevent crop water stress at SCAL the effective rooting depth early in the growing season from planting to six- or eight-leaf (V6 or V8) stage should be 12 inches; from V8 to R1 it should be 18 to 24 inches; from R1 to R5 it should be 36 inches; and from R5 to R6 it should be 48 inches.

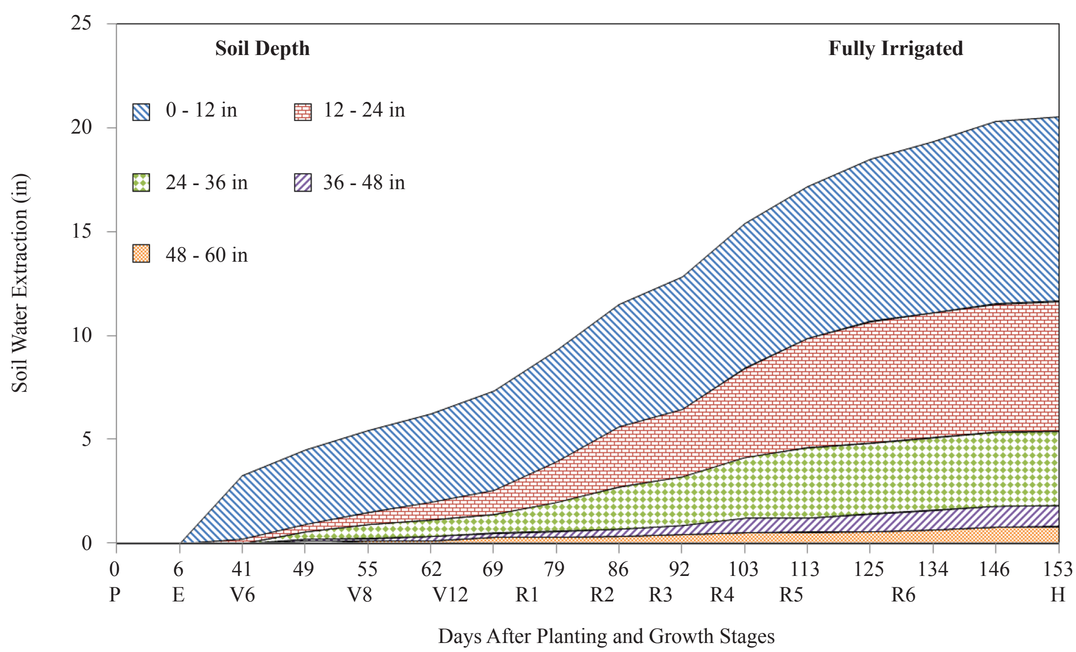

Figure 2. Cumulative individual soil layer water extraction amounts (inches) with 12-inch increments down to 60 inches with respect to days after planting (DAP) and corn growth and development stages in 2012, under non-stressed water and nutrient conditions. The soil at SCAL is a Hastings silt-loam soil with a water-holding capacity of 2.2-2.3 inches per foot.

Table III. Average soil-water extraction amounts (inches) for 12-inch depths and total profile (0-60 inches) for different corn growth stages and days after planting (DAP) at the University of Nebraska–Lincoln South Central Agricultural Laboratory (SCAL), under non-stressed water and nutrient conditions in 2012. Values correspond to *Figure 2*.

		Soil Depth (inches)						
Growth Stage	*DAP**	*0 - 12*	*12 - 24*	*24 - 36*	*36 - 48*	*48 - 60*	*Profile*	*Total in Profile*
Emergence (VE)	6	0	0	0	0	0	0	0
6-Leaf (V6)	40	3.0	0.2	0.0	0.0	0.0	3.2	3.2
8-Leaf (V8)	54	0.9	0.4	0.6	0.1	0.1	2.1	5.3
12-Leaf (V12)	64	0.5	0.4	0.2	0.1	0.1	1.3	6.6
Silking (R1)	75	0.7	0.7	0.4	0.1	0.1	2.0	8.5
Blister (R2)	84	0.6	1.0	0.6	0.1	0.0	2.4	10.9
Milk (R3)	90	0.5	0.5	0.4	0.1	0.1	1.5	12.4
Dough (R4)	96	0.4	0.5	0.3	0.1	0.1	1.4	13.8
Dent (R5)	110	0.6	1.4	0.7	0.2	0.1	2.9	16.7
Mature (R6)	130	0.8	1.0	0.2	0.2	0.1	2.3	19.0
Harvest (H)	153	0.9	0.3	0.1	0.1	0.2	1.6	20.6

*DAP: Days after planting (visually observed at SCAL in 2012).

Irrigation and Nutrient Management

Soil moisture sensors are becoming more widely accepted and used for irrigation scheduling. Placement of sensors should be in representative areas for a field or management zone and the depths sensed should reflect the effective rooting depth for a given crop within that zone in a given soil type. Irrigation can then be scheduled to prevent crop water stress and/or nutrient stress, given the availability of soluble nutrients, such as NO_3-N, is indirectly related to crop water availability. Furthermore, the distribution of nutrients within the soil profile may not coincide with water availability and therefore, the crop can be subjected to nutrient and/or water stress. Information on water and nutrient availability within the effective rooting depth would enhance both irrigation and nutrient management.

Summary

Crop soil-water extraction is the amount of water removed from individual soil layers as a result of root water uptake and/or soil evaporation (E) at the surface. Extraction patterns are affected by several factors, including crop type and growth stage; climate; and water, nutrient, and land management practices, along with others. Knowledge and history of soil-water extraction amounts and patterns can be used to determine effective rooting depth. This will aid in effective water and nutrient management practices, including proper soil moisture sensor placement for more effective irrigation scheduling as well as determining the effectiveness of irrigation applications in meeting the soil-water deficit of a given soil layer for optimum crop growth and yield.

Further Reading

Irmak, S., J.E. Specht, L.O. Odhiambo, J.M. Rees, and K.G. Cassman. 2014. Soybean yield, water productivity, evapotranspiration and soil-water extraction response to subsurface drip irrigation. *Transactions of the American Society of Agricultural and Biological Engineers (ASABE)* 57(3):729-748. DOI 10.13031/trans.57.10085.

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Rudnick, D.R., and S. Irmak. 2014. Spatial and temporal maize soil-water extraction (depletion) dynamics: Part II. Impact of water and nitrogen management strategies on soil-water extraction. *Transactions of the ASABE* 57(2):445-462.

Rudnick, D.R., and S. Irmak. 2014. Impact of nitrogen fertilizer on maize evapotranspiration crop coefficients under fully irrigated, limited irrigation, and rainfed settings. *J. Irrigation and Drainage Engineering, American Society of Civil Engineers (ASCE)* 10.1061/(ASCE)IR,1943-4774.0000778,0401403.

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