Soil Water Content and Thresholds for Irrigation

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ıe world is expected to reach 9 billion by 2050, and there is an urgent need to produce more food, feed and fiber to meet these ·iculture plays a pivotal role in supplying this demand. In the U.S., only 16 percent of cultivated croplands are irrigated, yet, this small nt of crop revenues. Simultaneously, the irrigated croplands use a large amount of water to maintain a maximum yield of crops. ıch Irrigation Survey (FRIS) conducted by the National Agricultural Statistics Service of United States Department of Agriculture,) acres of irrigated land. About half million acre-feet of water was applied in these fields in the survey year. The high water requirement es Oklahoma growers to continue improving irrigation management to maximize water and crop productivity.

ıgement, over- or under-irrigation may occur, leading to several negative environmental and economic impacts. In the case of over- y due to higher energy costs of pumping additional water without an economic increase in production. In addition, if the irrigation ɜar and tear will decrease the overall lifespan. Over-irrigation also may increase topsoil erosion and can cause the contamination of vements of water-soluble chemicals. But most importantly, over-irrigation depletes water resources, which could consequently :o drought. On the other hand, under-irrigation results in reduced yield of crops, which in turn, causes loss of revenue for growers and ı.

nted to achieve efficient and improved irrigation management. Examples include tracking crop water use based on weather data, using mperature and monitoring soil water status. It is best to use multiple methods (whenever available) to more accurately determine ater to apply. This fact sheet will focus on one of the most promising methods in irrigation management: soil water monitoring. In s used soil water monitoring sensors for irrigation scheduling (USDA, 2013). Hence, there is a great potential for improving irrigation se of advanced soil water monitoring sensors. To plan for irrigation scheduling, growers need to know how to interpret the numbers requires understanding of the basic soil water concepts and thresholds.

ral producers with the basic concepts of soil water and the thresholds utilized for proper interpretation of sensor data for efficient t irrigation management practices, producers can manage and conserve water, maximize the yield of crops and improve economic

l Water Content

il moisture is the amount of water present in the soil. It influences plant growth, soil temperature, transport of chemicals and ost widely used parameters for quantifying SWC or water availability for plants are i) volumetric water content; and ii) soil matric

ontent (VWC)

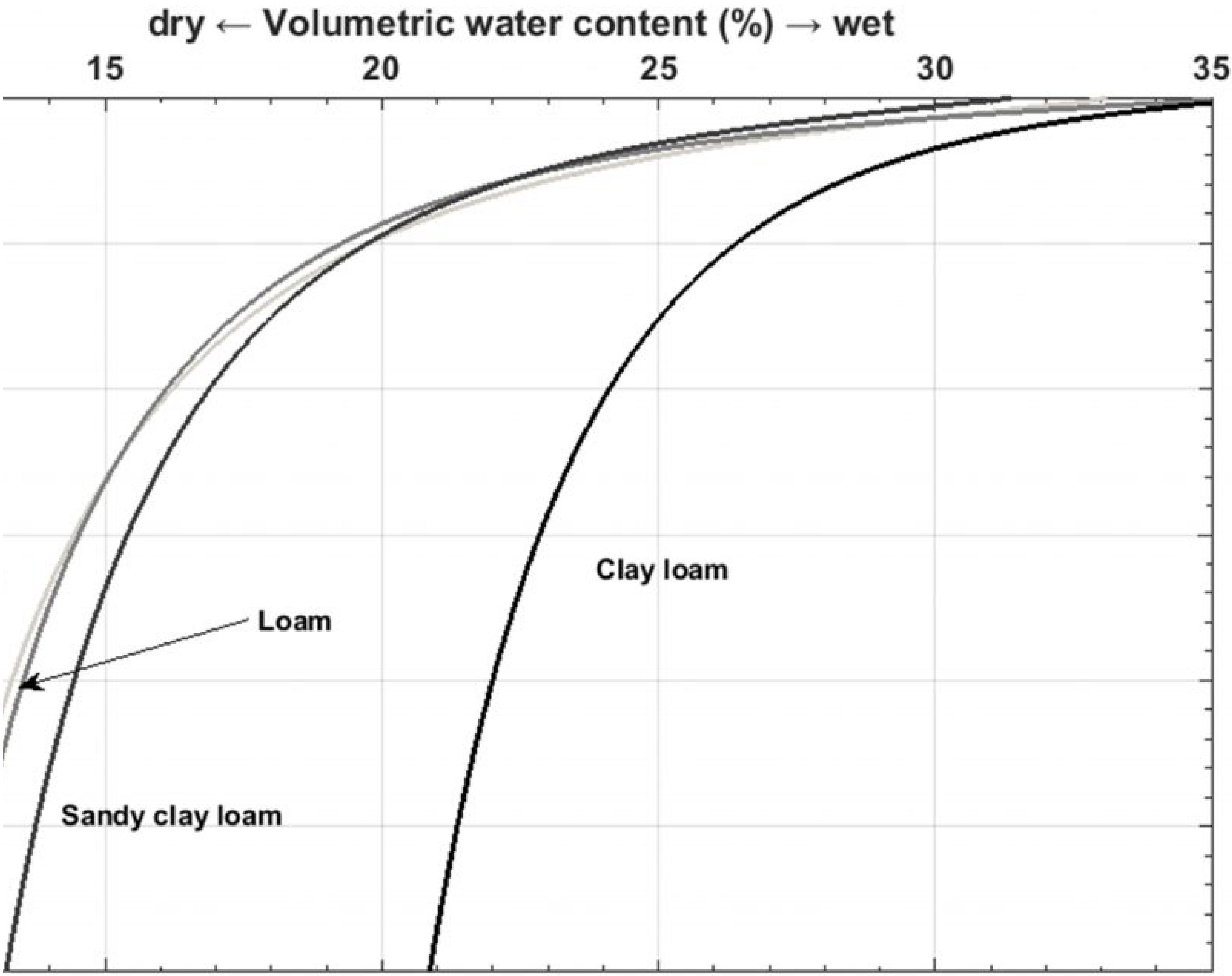
e ratio of the volume of water to the unit volume of soil. Volumetric water content can be expressed as ratio, percentage or depth of a unit surface area), such as inches of water per foot of soil. For example, if the volume of water is 20 percent of the unit volume of soil rted as 20 percent, 0.20 (ratio) or 2.4 inches per foot of soil (0.20 × 12 inches per foot).

al (SMP)

oil suction or soil water tension, represents the forces that bind water molecules to solid particles and to each other in soil pores, thus r through the soil matrix. Plants must apply a force greater than SMP to be able to extract water from the soil. As the water is removed is held more strongly, making it harder for the plant to extract water from the soil through its roots. The SMP increases as the water is plant. The SMP is expressed in two major units: kilopascal (kPa) and centibar (cb). One kPa is equal to one cb. Since SMP is a negative e a negative sign. However, some sensors and sources do not show the negative sign and report the magnitude of SMP without the

en VWC and SMP

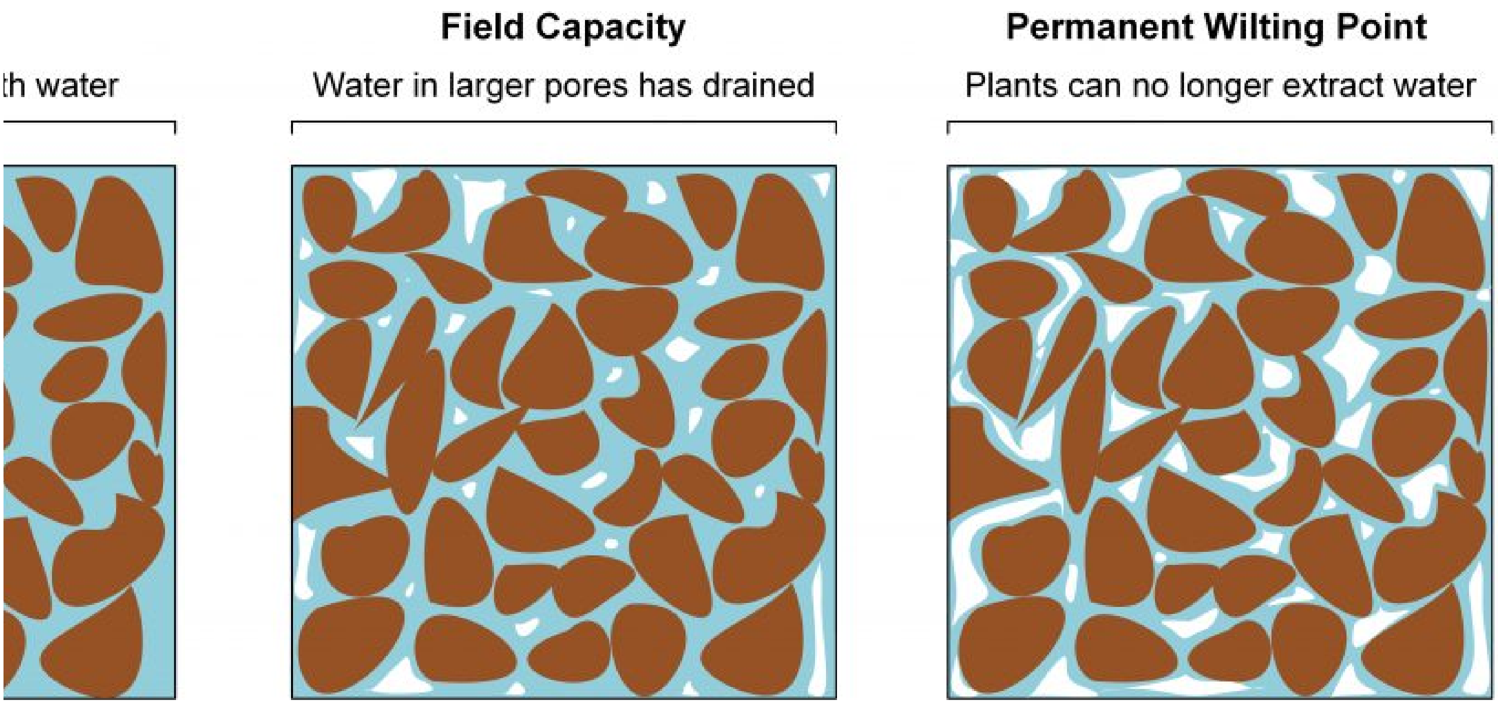
WC data in VWC format, while others report SMP. In some cases, it may be needed to convert between VWC and SMP. The relationship not linear, with most of the VWC changes occurring at SMP values of zero to 300 kPa. Beyond 300 kPa, the soil is too dry for the roots d VWC changes per unit change in SMP are significantly smaller. A soil water characteristics curve, also known as soil water retention ationship between VWC and SMP for a particular soil type. This curve can be used for converting VWC values to SMP and vice versa. duced during the conversion, especially if generalized curves are used rather than those developed for the specific soil where sensors oil water characteristics curves developed by OSU for four soils from central and southwest Oklahoma.



:s curves of four types of Oklahoma soils.

resholds

values of SWC indicating water availability for plant consumption. These thresholds are used to determine when and how much



turation, field capacity and permanent wilting point thresholds.

ıich all the pores (empty spaces between the solid soil particles) are filled with water. The VWC at this threshold varies from 30 percent y soils. The SMP at saturation is less dependent on soil texture and is close to zero, indicating that there is minimal restriction to water tract water from the soil with minimum energy.

ɔld at which water in larger pores has been drained away by the force of gravity. An irrigation application depth that causes SWC to go e the additional water will percolate to deeper layers and will not be available to plant roots. At FC, the water content of the soil is ɔwth. Thus, FC is usually considered as the upper threshold for irrigation management. Most agricultural soils reach field capacity one rainfall event. At this threshold, typical VWC varies from 20 percent in sandy soils to 40 percent in clay soils (2.4 to 4.8 inches per capacity varies from 10 kPa to 33 kPa. When salinity is a concern, increasing SWC to levels above FC may be appropriate to leach salts

is the threshold where it becomes impossible for plants to extract water at a rate fast enough to keep up with their water demand. At so strongly that it becomes difficult for plant roots to extract it. At this threshold, transpiration (water use by plants) and consequently vival come to a near stop. This causes a significant reduction in crop growth and yield of crops. If SWC remains below the PWP for an entually die. Irrigation should be applied well before SWC starts approaching the PWP. The value of PWP varies with the type of plant, ercent in sandy soils to 24 percent in clay soils (0.8 to 2.9 inches per foot) when expressed in VWC. The soil matric potential at this 00 kPa. The value of 1,500 kPa is usually considered as the average SMP at PWP for most agricultural soils.

e total amount of water available to plants, estimated as the difference between soil water content at FC and PWP. Above FC, water is period of time (one to three days), then lost to drainage. Below PWP, plants cannot apply enough force to extract the remaining water. ɔnsidered not available to plants. Sandy soils cannot hold a large amount of water and have the lowest amount of TAW, whereas, loam and silty clay loam have the largest TAW. Therefore, sandy soils need to be irrigated more often than loam soils. Although plants ange, stress occurs before SWC approaches PWP. Water must be applied at a SWC level above PWP to avoid water stress in plants.

, PWP and TAW for different types of soils sampled across the U.S., and Table 2 shows these values for agricultural soil samples taken ıoma. A comparison between values presented in these two tables shows differences in soil water thresholds for the same soil types. 1 represent U.S. averages and include a large variation due to diversity in soil types. Except for the loam soil, all other soil samples naller TAW compared to national averages. This suggests more frequent irrigations and smaller volumes may be required since city for holding water available to plants.

n (MAD) is the portion of the total available water (TAW) that can be depleted before plants experience water stress and potential
ield reduction). Although plants can extract water across the entire range of TAW, the cost is not the same. If TAW is depleted below
e water stress. The greater the depletion, the greater the water stress until PWP threshold is reached and a plant's vital processes

lds for different soil textures sampled across the U.S.

P	TAW (%)
	6
	9
	12
	15
	15
	20

n et al. (2000)

different soil types sampled in central and southwest Oklahoma.

NP (%)	TAW (%)
	12
	13
	11
	10

ere mainly a function of soil type, the value of MAD is a function of stress tolerance, growth stage and water use of the crop. This value
as some vegetables and is larger for crops that can tolerate higher water stress without affecting their yield. For example, a sensitive
meaning that it will start experiencing stress once 30 percent of the TAW is depleted. A less sensitive crop, such as cotton has MAD of
possible yield reduction) will occur at 65 percent removal of TAW. Table 3 shows typical values of MAD and maximum root zone depth
AD values represent average crop water use condition of 0.20 inch per day. If the crop water use is higher than 0.20 inch per day,
d to avoid stress.

MAD values provided in Table 3 are multiplied by TAW and then subtracted from FC to estimate irrigation trigger points. For sensors that
riggered at values presented in Table 4 for different types of crops. Irrigation must be applied when SMP values, recorded by soil water
ot depth reach or exceed limits in Table 4, depending on the climate. The smaller values of SMP are for a dry, warm climate and larger
.

epletions (MAD) and maximum root zone depths for selected crops.

ɅD*	Maximum root depth (ft.)**
5	3.3-5.6
5	3.3-4.5
0-5	2.6-6.0
0 – 5	3.3 – 6.6
	1.6 – 3.3

se of 0.20 inch/day

and other conditions. Effective root depth is usually shallower.

es at MAD for selected crops.

SMP (kPa or cb)
0 - 150
0 - 70
5 - 40
5 - 65
0 - 70
0 - 30

gations Based on Soil Water Content

nt primarily aims to control the depth and frequency of applied irrigation water to meet crop water requirements, while preventing urces. An effective approach to achieve this is to manage irrigations based on SWC information. The three major types of data required this approach are:

e of SWC at any given time must be known before any decisions on improving irrigation management can be made. Different types of soil water sensors
ability to provide SWC data in either VWC or SMP units. These sensors are significantly different in cost, accuracy and ease of installation and data
collecting SWC information is root depth, which varies with crop type; growth stage; soil type and physical restrictions such as hard-pans (compacted
ble 3). Crops with shallower rooting depths have reduced access to stored soil water and require more frequent irrigations than crops with deep roots.
it is important to have sensors at several depths across the effective root zone to obtain a complete picture of soil water dynamics. This is because
not necessarily mean the crop is undergoing water stress, as the plant roots can extract water from other soil layers.

ı be obtained from published tables (such as those in this publication) using soil texture information at the site of interest. Soil texture can be identified Water and Forage Analytical Laboratory at OSU through the local Extension office. The value of FC can also be determined using the soil water reading a ainfall event, if sensors were already installed and if the soil had reached saturation. Once FC and PWP are identified, TAW can be calculated (FC – PWP) information to schedule irrigation events. However, the value of FC alone can be very useful in the preliminary assessment of irrigation efficiency rom the bottom of the root zone. If the numbers reported by soil water sensors after irrigation events indicated that SWC was above the FC limit, water olation). The amount of water in excess of FC will not remain at the measurement depth to be extracted by plant roots. Going above the FC limit can be se the water percolating to lower levels will be still within the root zone. At deeper layers (close to the bottom of root zone), any drainage becomes a loss water, energy that was used to apply that water and many nutrients carried with water.

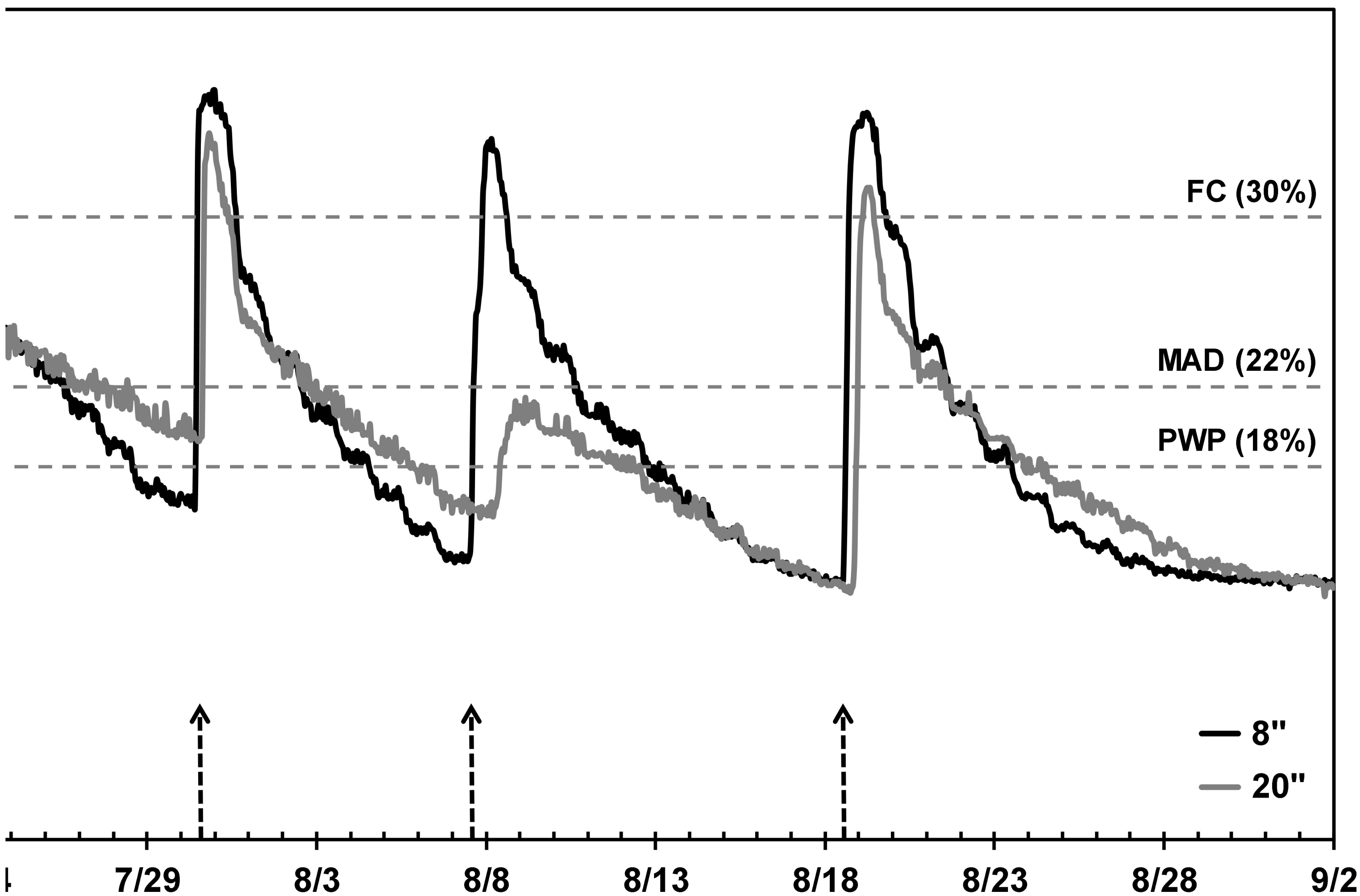
an be obtained from published tables based on the type of crop and its sensitivity to water stress. It can also be modified with time, based on ct of different MAD values on crop yield. If the goal is to avoid even small stresses, then irrigation should be applied as soon as SWC reaches the MAD SWC exceeds FC. In situations where an irrigation decision must be made in advance (for example to request water delivery or to allow the irrigation the time it will take to reach MAD can be predicted based on SWC fluctuations in previous days and forecasted weather conditions. In some cases, it is oil water to drop below MAD. Examples include crops, such as grape that require some level of water stress to reach a specific chemical concentration example is during late growing stages, when experiencing some water stress does not affect yield.

e data mentioned above is somewhat different depending on how SWC is reported by soil water sensors (VWC or SMP). The following rpreting SWC data collected from two cotton fields in central and southwest Oklahoma, one based on VWC and the other based on

gations based on VWC data

s of VWC monitored by soil water sensors at two depths for a period of 45 days during summer 2016. Irrigation water was applied using ted on the center of the beds. Arrows represent irrigation dates and dashed lines mark soil water thresholds.

andy clay loam, with FC of 30 percent and PWP of 18 percent. The total available water (TAW) can be calculated as: TAW = (FC – PWP) = rcent or 1.4 inch per foot.



s at 8 and 20 inches below soil surface over a 45-day period.

m Table 3 as 0.65. This is equal to 8 percent when multiplied by the TAW (12 percent × 0.65 = 8 percent). In other words, the largest can be depleted from the root zone of the crop below field capacity before stress occurs is 8 percent. Therefore, soil water content ow 22 percent (30 percent – 8 percent) in the effective root zone if the goal is to avoid any stress. The effective root zone depth is one and might change, depending on water stress the plant is facing and the crop growth stage. When the upper portion (near the e plants have the ability to extract water from deeper layers with larger water content.

ions were applied during the studied period. The first irrigation event, around July 22, took place when the volumetric water content at was below MAD, suggesting that cotton was under some stress when irrigation was applied. The irrigation event brought the VWC ter percolated below both layers. However, cotton roots go deeper than 20 inches and the drained water may have not necessarily it remained at lower layers within the root zone. Soon after this irrigation SWC started declining, with a rapid phase during the first two er July 24. On July 26, the 8-inch layer became dryer than then 20-inch layer because it is shallower and prone to larger evaporation

ly 30 was similar to the first in terms of increase in SWC and the rate of water depletion. The third event on August 7 was somewhat not respond in the same way. This could be likely due to applying a smaller amount of irrigation water – not enough to saturate the 20- had a smaller increase that did not even reach the MAD threshold. Hence, no water was lost to deep percolation below this layer. The to the first two events in terms of changes in soil water content.

d at this site indicated irrigation management was fairly efficient, with some deep percolation below 20 inches that may have been t zone. Some water stress may have occurred in between irrigation events as SWC dropped below MAD and even PWP for short periods. y suggest a decline in crop yield, since stress periods did not last too long. In addition, the entire root zone should be considered, since eper soil, which has a greater water content and compensate for water deficiency at shallower layers. Adding sensors at deeper layers

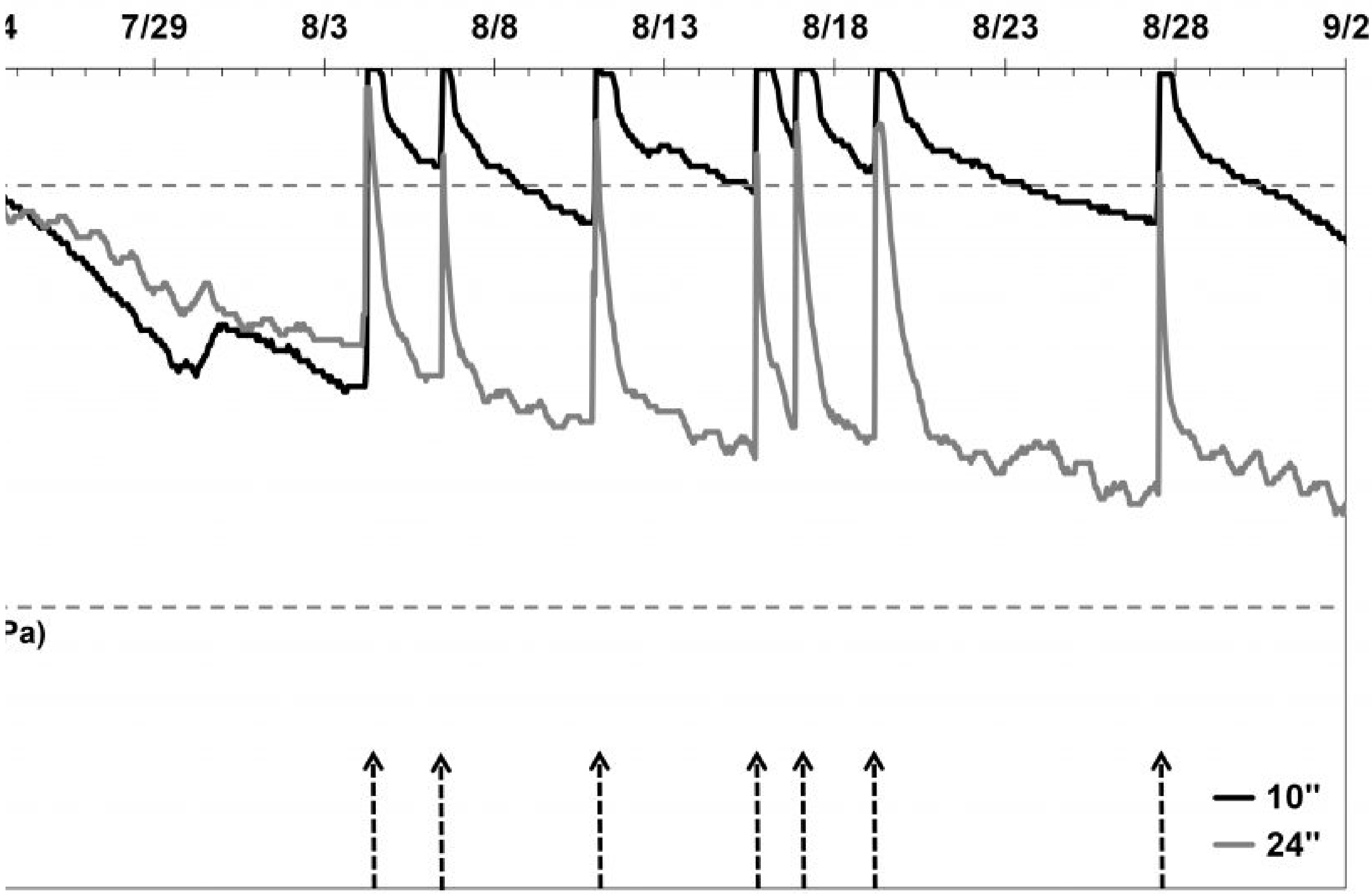
help better evaluate the effectiveness of irrigation applications. The data suggest that increasing the amount of water applied in each
iding stress since with current amounts SWC exceeded FC and thus any additional water could be lost to drainage. In this case,
ssible) would be more effective in minimizing stress.

gations based on SMP data

:tuations of SMP monitored by soil water sensors at two depths during a period of 45 days in the summer of 2015. Irrigation water was
r (center-pivot) system. Arrows represent irrigation/precipitation dates and dashed lines mark soil water thresholds.

oam, with the FC of 25 percent and PWP of 11 percent. The TAW was 14 percent (24 percent – 11 percent). The MAD for cotton is 0.65.
r that can be depleted below FC was 9 percent (14 percent × 0.65). The VWC level for triggering irrigation events is 16 percent (25
il water sensor used in this case provided SWC estimates in SMP, calculated thresholds were converted from VWC to SMP, using the
Figure 1). The SMP value at FC was 23 kPa and at the MAD was 105 kPa. The estimated MAD is consistent with the range of 100-120
).

ls, irrigations should have been managed to keep the SMP in between 23 and 105 kPa to avoid water loss and stress. According to
nained above FC for most of the study period (after Aug. 4), indicating that water was lost to drainage below 10 inches. However, the
lost to the crop since the 24-inch layer was below FC at most times, except a few days at the beginning of the study period. As stated
ve been triggered at SMP of about 105 kPa. However, the SMP at the 10- and 24-inch layers never exceeded 68 and 87 kPa,
these two layers ranged from zero to 60 kPa. Hence, irrigation intervals could have been longer without affecting crop yield. A lower
als) would have resulted in smaller energy use for pumping water, as well as smaller evaporation losses from wet soil and crop



s at 10 and 24 inches below the soil surface over a 45-day period.

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