Technical Bulletin TB08-02

Agricultural Experiment Station

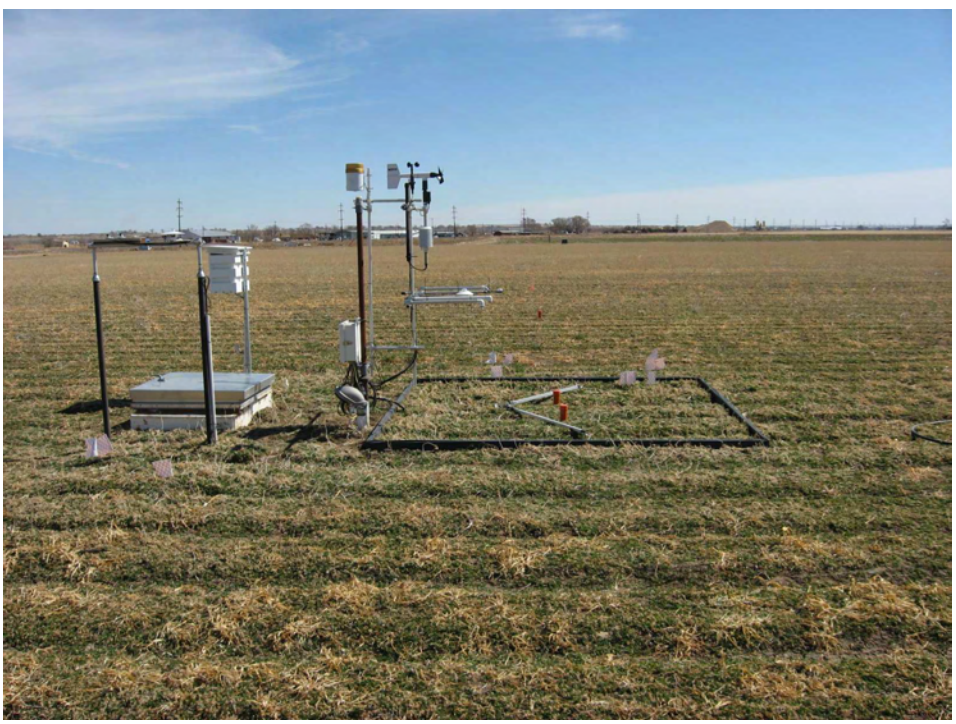
Colorado State University

College of Agricultural Sciences

Department of Soil and Crop Sciences

Arkansas Valley Research Center

The Large Lysimeter at the Arkansas Valley Research Center: Objectives and Accomplishments



The Large Lysimeter at the Arkansas Valley Research Center: Objectives and Accomplishments

Abdel Berrada[1], Lane Simmons[1], Dale Straw[2], Michael Bartolo[1], and Thomas Ley[2]
[1]Colorado State University, Arkansas Valley Research Center, Rocky Ford, CO
[2]Colorado Division of Water Resources

Author contact: Abdel.Berrada@Colostate.EDU

Lysimeter project contact: Lane.Simmons@Colostate.EDU

Colorado State University Agricultural Experiment Station Technical Bulletin TB08-02

Funding for the lysimeter project was provided by the Colorado Water Conservation Board, the Colorado Agricultural Experiment Station, and the Colorado Water Resource Research Institute.

Cover: Large lysimeter, access hatch, and various meteorological instruments. Photo taken by Thomas Ley on March 12, 2008.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

The Large Lysimeter at the Arkansas Valley Research Center: Objectives and Accomplishments

Abdel Berrada[1], Lane Simmons[1], Dale Straw[2], Michael Bartolo[1], and Thomas Ley[2]
[1]Colorado State University, Arkansas Valley Research Center, Rocky Ford, CO
[2]Colorado Division of Water Resources

Rationale and objectives:

One of the recommendations that came out of the Kansas v. Colorado Arkansas River Compact litigation is for Colorado to use the ASCE Standardized Penman-Monteith equation (Walter et al., 2000) to estimate crop consumptive use in the Arkansas River Valley. The Penman-Monteith equation (PME) calculates the evapotranspiration (ET) of a reference crop, which in Colorado is alfalfa, using meteorological data such as maximum and minimum temperature, relative humidity, solar radiation, and wind speed. The ET of other crops (ETc) is derived from reference ET (ETr) with the equation:

ETc = ETr x Kc for well-watered crops.

ETr is defined as the evapotranspiration of a non-stressed, well watered alfalfa crop, 50 cm in height, covering the ground fully. In other states, the reference ET is that of a non-stressed grass or similar short crop that is 12 cm in height at full canopy and is usually denoted ETo.

Kc or crop coefficient varies with crop type, growth stage, crop condition (plant density, health, etc.), and soil wetness, among other things. When the crop is water-stressed,

ETc = ETr x Kc x Ks

The water-stress coefficient Ks can be calculated with the equation:

Ks = (TAW – Dr)/[(1-p) TAW]

where Dr is the root zone water depletion (mm), TAW is the total available water in the root zone (mm), and p is the “fraction of TAW that a crop can extract from the root zone without suffering water stress” (Allen et al., 1998). Methods and examples of calculating Kc, Ks, and crop ET are given in FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). Some of the estimates are based on the water balance method,

$$ET = I + P - RO - DP + CR \pm \Delta SF \pm \Delta SW$$

where I is irrigation depth, P is precipitation (water from rain or snow), RO is runoff, DP is deep percolation, CR is capillary rise from a shallow water table, ΔSF is the change in subsurface (horizontal) flow of water, and ΔSW is the change in soil water content. All the terms of the equation are expressed in inches or millimeters. The horizontal flow of water in and out of the root zone, and CR, DP, and RO may be hard to measure; although DP and RO can be minimized or eliminated with efficient irrigation systems and sound irrigation scheduling. Runoff occurs when water (from irrigation, rain, or melting snow) application rate exceeds soil infiltration rate, particularly in sloping terrain. Given the uncertainties in measuring some of the components of the water balance equation, this method only gives good estimates of ET over long periods of time e.g., one week or longer.

Direct measurement of ET is best achieved with weighing lysimeters. Precision weighing lysimeters measure water loss from a control volume by the change in mass with an accuracy of a few hundredths of a millimeter. Non-weighing lysimeters are more common but they “are not considered suitable for reference ET equation verification and crop coefficient research. They may, however, be very suitable low cost alternatives for studying the effects of varying water salinity levels and high water table conditions on crop ET up and down the Arkansas River Valley.” (Ley, 2003).

In the absence of locally generated algorithms for calculating ETr with PME and Kc, the Colorado Division of Water Resources (DWR) has been using estimates from Kimberly, ID and Bushland, TX. However, the crop growing conditions (soil, elevation, climate, etc.) in the Arkansas Valley vary greatly from the prevailing conditions in Kimberly or Bushland. In his findings relating to the Arkansas River Compact compliance litigation initiated by Kansas, Special Master Arthur Littleworth accepted that the method used for calculating crop consumptive use in the Arkansas Valley be changed from Blaney-Criddle to PME. Consequently, Colorado’s Attorney General requested that the Colorado Water Conservation Board (CWCB) fund the “design, installation, and operation of weighing lysimeters at the Colorado State University Agricultural Experiment Station at Rocky Ford, Colorado”. The requested funds also cover the enhancement of CoAgMet weather stations, the investigation of irrigation water management in the Arkansas Valley, and the review of the changes made to the Hydrological-Institutional (H-I) Model by experts. The H-I Model has been used by the State Engineer’s Office (DWR) to determine depletions to usable water flows to Kansas.

Colorado State University (CSU) has a network of twelve automated weather stations along the Arkansas Valley. Temperature, solar radiation, humidity, and wind speed data from these stations will be used to validate ETr and Kc estimates for the whole valley.

The lysimeter project at the Arkansas Valley Research Center (AVRC) consists of one large lysimeter and one smaller reference lysimeter. The large lysimeter was installed in 2006 and the reference lysimeter will be installed in 2008.

The project objectives, according to Thomas Ley of DWR (2003), are to:

1. Evaluate the performance and predictive accuracy of the ASCE Standardized PME for computing alfalfa reference crop ET for the growing conditions in southeastern Colorado,
2. Determine crop coefficients (for use with PME) for the various crops grown in the Arkansas River Valley under well-watered conditions, and,
3. Determine the effects of typical local growing conditions (which may include limited irrigation, high water table conditions and irrigation with water of high salinity contents) on crop water use.

The latter objective may require additional lysimeters, e.g., non-weighing ones to achieve. It is worth noting that the effects of limited irrigation, high water table, and salinity on crop growth and water use in the Arkansas Valley have been studied by CSU scientists for several years using traditional (water balance estimates) and non traditional (remote sensing) methods. However, the impact of salinity, for example, on crop water use, can be determined more accurately with a weighing lysimeter. Relatively high salt levels have been reported in the soils and waters of the Arkansas Valley (Gates et al., 2006).

The installation of the large lysimeter was completed in the fall of 2006, but some of the meteorological sensors were put in place in 2007. Consequently, it will be two to three years before objective no. 1 is achieved and several more years before usable Kc values and formulas are developed for the major crops grown in the Arkansas Valley.

The remainder of this report contains a description of the large lysimeter and its location, a brief review of field operations and irrigation methodology, and future plans.

Site characteristics:

The large lysimeter is located at the Arkansas Valley Research Center, approximately two miles east of Rocky Ford in Otero County, Colorado (NW1/4 Sec 21, T23S, R 56W). The elevation at the site is approximately 1,274 m, latitude: 38° 2′ 17.30″, and longitude: 103° 41′ 17.60″. The soil type is Rocky Ford; coarse-loamy, mixed, superactive, mesic Ardic Argiustoll. Selected soil properties are shown in Tables 1 and 2.

The long-term average annual precipitation at the site is 11.8 inches, with May through August having the highest rainfall. The total average annual snowfall is 23.2 inches. The average minimum temperature is 36.3 °F and the average maximum temperature 70.0 °F. The last spring frost (32.5 °F) occurs on or before May 1 and the first fall frost on or after October 5 in 50% of the years; thus the average length of the growing season for warm-season crops like corn is 158 days (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?corock).

Lysimeter characteristics:

The large lysimeter consists of an inner tank of 10 ft x 10 ft x 8 ft (3 m x 3 m x 2.4 m) and an outer containment tank. The chamber between the two tanks houses the weighing mechanism, the drainage tanks, and data loggers and has standing room for a half-dozen people. The inner

Table 1. Soil characteristics of the large lysimeter site.

Horizon	Depth (cm)	Textural class	pH water (1:1)	CEC (meq/100 g)	ECe (dS/m)	Total C g/kg	SAR
Ap	0-23	Clay loam	8.1	17.2	0.82	15.5	1.70
Bt	23-36	Clay	8.0	16.9	0.90	14.8	2.08
Btk	36-100	Loam	8.3	10.0	0.58	9.0	2.46
Bk1	100-170	Loam	8.3	10.9	0.72	9.5	2.40
Bk2	170-230	Clay loam	8.3	13.5	0.88	10.8	2.18
2C	> 230	Course sand	8.7	1.5	-	1.7	-

Table 2. Soil bulk density and hydraulic properties (calculated).

Horizon	Depth (cm)	Bulk density (g/cm^3)	Matric suction in J/kg							Hydraulic conductivity (cm/hr)
			1500*	1500	1000	500	100	33	10	
			Water content by weight (g/kg)							
Ap	0-23	1.36	108	123	131	144	182	214	254	0.34
Bt	23-36	1.36	126	124	132	145	182	213	252	0.33
Btk	36-100	1.45	65	77	84	97	134	167	213	1.25
Bk1	100-170	1.43	70	82	89	103	141	176	224	1.06
Bk2	170-230	1.35	110	118	126	141	183	219	266	0.42
2C	> 230	1.86	11	19	22	26	40	53	73	16.9

*Water contents in this column were measured in the laboratory. The soil characterization data was provided by Dr. Lorenz Sutherland, Area Resource Conservationist, La Junta, CO 81050.

tank was filled with undisturbed soil (soil monolith) from an area approximately 350 ft from where the lysimeter is located (Fig. 1). The tank plus soil (soil tank) weighed approximately 100,000 pounds and it took two cranes to lift it off the ground and flip it upside down in order to install drainage pipes at its bottom (Fig. 2). Approximately 4 inches of fine sand was added to the bottom of the soil monolith to facilitate water drainage. The soil tank was later moved to its permanent location and set on a steel frame inside the outer tank (Figures 3-5). The soil tank moves freely within the outer tank and the two are separated at the top by a fraction of an inch. The enclosure top, also called the top hat, was welded to the outer tank in situ to ensure a tight fit (Fig. 6). The lips of the soil tank and the top hat were covered with a thin rubberized material to prevent water from getting into the narrow gap between them, without restricting the movement of the soil tank (Fig. 7).

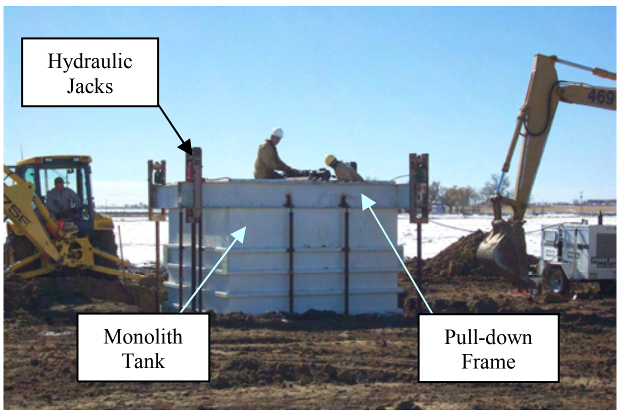


Figure 1. The inner tank being pushed into the ground to acquire the soil monolith. Photo by Dale Straw of DWR.

Figure 2. The inner tank plus soil being lifted off the ground prior to moving it to its permanent location. Photo by Abdel Berrada.

Figure 3. The outer tank being lowered into position. The concrete slabs were used to hold the soil in place. They were taken out before re-filling the empty space around the outer tank. Photo by Dale Straw of DWR.

Figure 4. The inner tank plus soil being lowered inside the containment tank. Photo by Michael Bartolo.

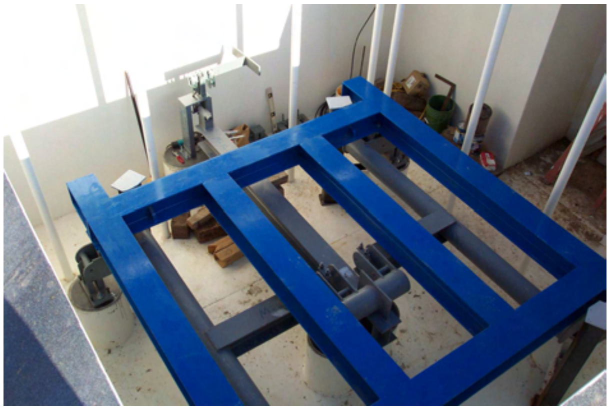


Figure 5. Steel support frame for the soil tank. This photo also shows the scale.

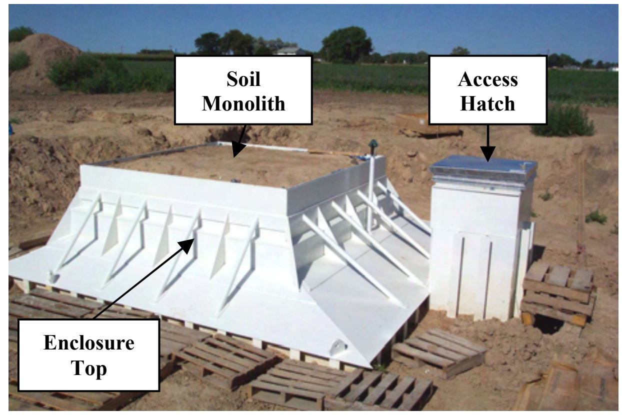


Figure 6. Enclosure top and access entry to the chamber between the inner and outer tanks.

Figure 7. View of the large lysimeter after the soil around it was repacked.

The weighing mechanism consists of a mechanical lever scale-load cell combination (Fig. 8). The load cells are connected to Campbell Scientific CR-7 data logger which records the weight of the inner tank plus soil every 10 seconds. The readings are given in millivolts per volt (mV/V). Precipitation from rain as measured by a tipping bucket rain gauge mounted on a steel pole next to the lysimeter is also recorded. An example of load cell and precipitation readings is shown in Figure 9. Water that percolates through the soil monolith is collected in two drainage tanks (Fig. 10) suspended from the scale frame that supports the soil tank, so that there is no overall weight change as water drains into the tanks. One tank collects water from the internal portion of the monolith and the other tank collects water from the perimeter of the monolith.

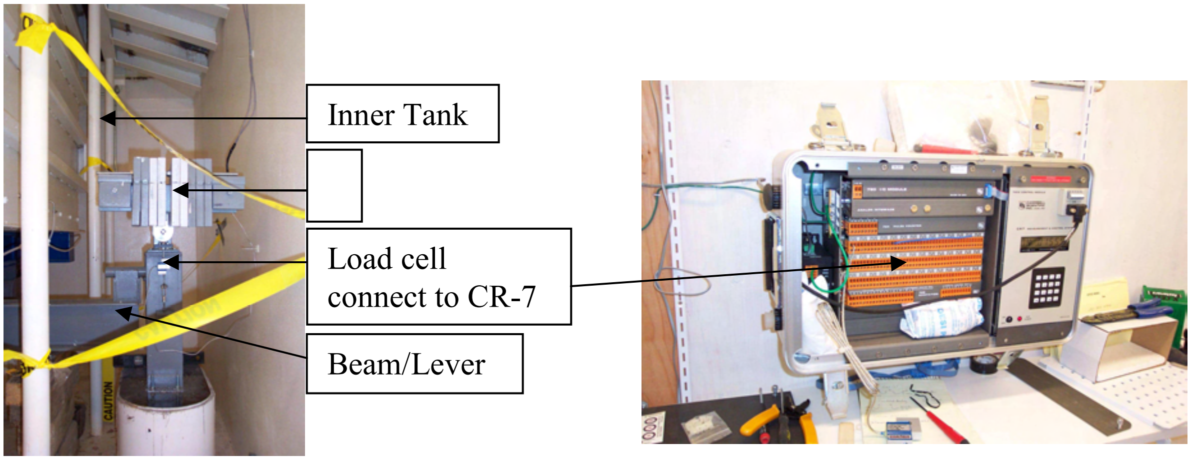


Figure 8. Weighing mechanism and CR-7. Photos by Dale Straw of DWR.

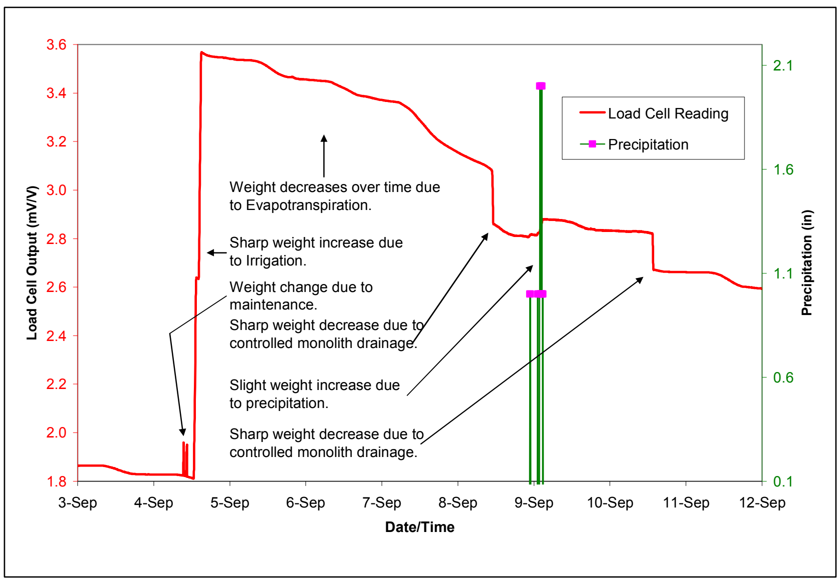


Figure 9. Load cell and precipitation readings for 3-12 Sept. 2006. Graph by Lane Simmons

Figure 10. Vacuum pump and drainage tanks. Photo by Dale Straw of DWR.

Calibration of the load cell output:

A thorough calibration was performed in 2006 to convert the load cell output in mV/V to the weight of water in kilograms. The procedure was similar to the one developed by USDA-ARS at Bushland, TX (Howell et al., 1995). The mass in kilograms and number of weights (in parenthesis) used in the calibration was as follows: 320 (9), 22.68 (2), 4.5 (20), 2 (1), 1 (1), 0.5 (1), 0.2 (1), 0.1 (1), and 0.05 (1). Weights were placed on and removed from the surface of the inner tank + soil in a predetermined order and load cell readings were recorded after the lysimeter was stabilized following the application or removal of each weight (Fig. 11).

Figure 11. Lysimeter weight calibration.

The response was linear from zero to maximum loading and similar for the various tests (Table 1 & 2 in Appendix A). Figure 12 shows the response at the low end of the load cell readings. The coefficient (slope of the regression line) determined for application to the change in load cell readings as the lysimeter gains or looses mass is 685 kg/mV/V, which is equivalent to a change of 76 mm of water on the lysimeter for a change of 1 mV/V in the load cell output. The standard deviation of the weight measurements (accuracy) was less than 0.02%. After calibration, a 320 kg weight was applied in turn to each corner of the lysimeter surface to large for the effect of uneven loading. No difference in load cell readings was observed for the total lysimeter weight as the 320 kg weight was located at each corner.

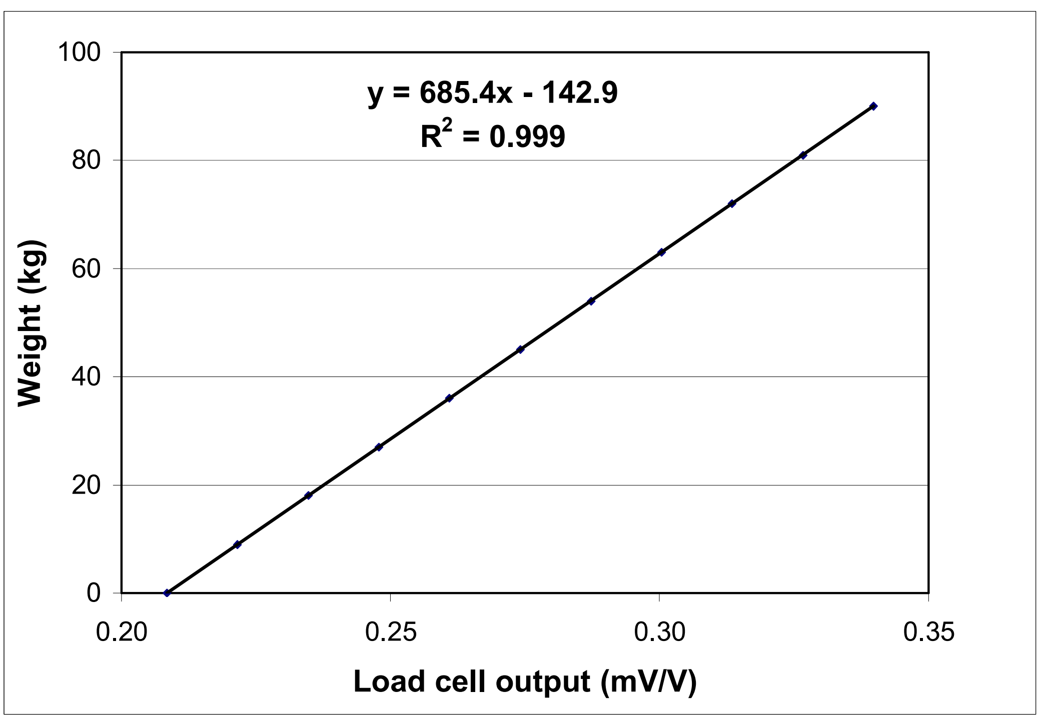


Figure 12. Weight as a function of load cell output. The calibration data was analyzed by Dale Straw of DWR.

Instrumentation:

Several sensors are used to monitor the atmospheric, crop, and soil conditions above, inside or outside the soil monolith. Sketches showing the location of each sensor are available at AVRC. Some parameters are measured with more than one sensor for comparison or verification purposes. Data from these measurements will be used to calibrate the Penman-Monteith equation (Allen et al., 1998).

Weather measurements:

- Rainfall is measured by the TE525 tipping bucket rain-gauge mounted on a metal post, 2 meters above ground. Each tip of the bucket equals 0.01 acre-inch of precipitation.
- Wind speed, in meters per second, is measured by the RM Young 03101 Wind Sentry cup anemometer. **Wind direction** is measured by the RM Young Wind Monitor (prop-anemometer). It is given in degrees, where 0 degree = north and 180 degrees = south. The RM Young Wind Monitor also measures wind speed.
- Ambient air temperature, in degree Celsius, and **relative humidity** in % are measured by the HMP45 sensor located in the radiation shield. Another humidity and temperature sensor, the Vaisala HMT331 is located in the 'cotton' shelter, along with the **barometric pressure** (in millibar) transmitter Vaisala PTB101B.
- Net radiation (Watts/m^2) is measured with the REBS Q7 net radiometer mounted on the radiation stand, north of the monolith.

Crop-related measurements:

- **Incoming** (from the sun) and **reflected** (from the ground or plants) radiation is measured with the K&Z pyranometer CM14 mounted on the arm/mast extending over the monolith (Fig. 13). A Li-Cor pyranometer and a Li-Cor Quantum sensor mounted on the radiation stand also measure the incoming or incident radiation.
- Reflected photosynthetic active radiation (PAR), in µmol $s^{-1}m^{-2}$, is measured with a Li-Cor Quantum sensor mounted on the arm/mast above the monolith.
- Crop temperature is measured with two separate sensors located over the monolith. One sensor measures the temperature of the target's surface (crop canopy) at an oblique angle and the other sensor measures the temperature of the target's surface straight down (nadir). Both sensors are infrared temperature sensors and are mounted on the arm/mast above the monolith. The temperature of the body of each sensor is also measured and used to correct the crop canopy temperature.

Soil measurements:

- Soil Temperature: There are 14 temperature sensors located inside the soil tank and six outside. Of the monolith sensors, four were placed at 10 mm below the soil surface, four at 40 mm, two at 0.5 m, two at 1.0 m, and two at 2.0 m. Six sensors were placed few feet away from the lysimeter at 0.5-, 1.0-, and 2.0-m depths (two sensors per depth).
- Heat Flux or the amount of heat moving in or out of the soil is measured with flux plates placed at 100 mm below the surface of the monolith. Two are in the 3rd furrow from the west and two in the 3rd full bed from the west.

- Soil Moisture: Two 1.5-in diameter electromechanical steel tubes (EMT) were installed in the soil monolith (Fig. 13) and four outside the monolith (one in each direction) to monitor soil water content with the CPN 503DR neutron probe at 10, 30, 50, 70, 90, 110, 130, 150, 170, and 190 cm depths.

Figure 13. Neutron probe access tube placement in the soil monolith after it was seeded to alfalfa. The tops of the access tubes are covered with capped PVC pipes painted in orange. The white flags mark the location of various sensors. Two Li-Cor Line Quantum sensors lay between the access tubes.

Calibration of the neutron probe:

The CPN 503DR HYDROPROBE operates by emitting radiation from an encapsulated radioactive source, Americium-241:Beryllium. The high-energy neutrons emitted from the radioactive source are moderated (slowed down) by colliding with atoms in the soil. Only the low-energy, moderated neutrons are detected by the Heluim-3 detector and the data is displayed on the surface of an electronic assembly board as counts per unit-time or another unit of interest such as inches of water per foot of soil. The display board is integral to the source shield assembly, which also include a cable and a shield box (503 DR HYDROPROBE MOISTURE GAUGE OPERATING MANUAL, CPN INTERNATIONAL, INC., Martinez, CA). Hydrogen is "by far the most effective element for slowing neutrons, and because rapid changes in soil H content are almost completely due to changes in soil water content, the count of slow neutrons is proportional to soil water content." (Evett et al., 2003). The probe is lowered into an access tube to assess soil water content at various depths. The CPN 503DR Hydroprobe comes with a laboratory calibration to convert slow neutron count into soil water content. Field calibration is recommended since the laboratory calibration only uses two data points (wet and dry) and the measurements are done in a sand media. It is also a good idea to do a separate calibration for neutron probe readings at depths < 30 cm from the soil surface due to the potential loss of neutrons to the air. For the early neutron probe designs, Evett et al. (2003) reported that the majority of slow neutrons were measured from a nearly spherical volume of 20-cm (saturated soil) to 40-cm (dry soils) in radius.

The CPN 503DR probe was calibrated in 2007 based on the method developed by Evett et al. (2003). Two sets of 98-in long, 1.5-in inside diameter or approximately 1.7-in outside diameter (O.D.) electromechanical steel tubes (EMT) were installed in the fallow ground next to the lysimeter field on 23 August 2007. Each set consisted of three tubes, approximately 6 ft apart. The two sets were labeled ‘dry’ and ‘wet’ and were separated by about 30 feet of fallow ground. Shortly before installing each access tube, a hole was drilled in the ground with a hydraulic probe fitted with a 1.625 O.D. soil tube. The distal end of each access tube was crimped to facilite its insertion into the hole. The hole was about the same size as the O.D. of the access tube; therefore, it was necessary to push the tube into the hole by tapping with a hammer on a 4”x4” block placed on top of the tube. This ensured a tight fit between the outside wall of the access tube and the soil. Both ends of the access tube were plugged with rubber stoppers to prevent water and debris from entering the tube. Each tube extended 6 inches (~15 cm) above the soil surface. A depth control stand as described by Evett et al. (2003) was built by Lane Simmons and used when measuring soil water content with the neutron probe, i.e., to ensure that the measurements are made at the same depth relative to the soil surface (Fig. 14).

Figure 14. The neutron probe CPN 503DR sitting on top of the depth-control stand. Photo by Lane Simmons.

After installing the access tubes, an area of approximately 20 ft x 8 ft surrounding the wet set was diked and ponded with water on 24 August 2007 (Fig. 15). Water was added on 4 September and 7 September to create high soil water conditions and differentiate the ‘wet’ set from the ‘dry’ set to which no water was added. On 11 September, a trench was dug next to the access tubes in the dry set, with a back-hoe, to facilitate soil sampling. The few inches of soil closest to each tube were trimmed with a shovel to expose the front side of the tube. In order to minimize soil water loss by evaporation, only few feet of tube were exposed at a time and soil samples were taken shortly thereafter. The tube was marked with a permanent marker at 10, 30, 50, 70, 90, 110, 130, 150, 170, and 190 cm below the soil surface (Fig. 17). Soil samples were then taken with the Madera Probe (Fig. 17) at two locations above and two locations below (on each side of the tube) each depth. The soil samples (60 cm^3 per sample) were stored in Ziploc bags for ease of use and tare weight uniformity. The next day, soil samples were taken from the wet set using the same procedure. A total of 240 soil samples (3 tubes/set x 2 sets x 10 depths/tube x 4 samples/depth) were collected.

Figure 15. Water being added to the 'wet' set of neutron probe access tubes. The 'dry' set is in the background. Photo by Lane Simmons.

Figure 16. Measuring soil depth before taking soil samples. Photo by Kevin Tanabe.

Figure 17. Soil sampling with the Madera Probe. Photos by Michael Bartolo.

The samples were weighted within an hour or two of sampling and left to dry in the greenhouse (with the Ziploc bag open) for several days before transferring the soil to steel cans and drying them in the oven for eight hours at 105 ^{o}C. (Drying time was adequate since the soil was already quite dry by the time it was transferred to the steel cans). The empty weights of the Ziploc bags and the steel cans and the fresh and oven-dry (OD) weights of the soil were recorded. <u>Note:</u> It would have been easier to use steel cans from the start, but there were not have enough cans or lids.

The water content of each soil sample was calculated as follows:

Soil water content on a mass basis:

θ_m (g g^{-1}) = (soil fresh weight – tare) – (soil OD weight – tare)/(soil OD weight – tare)

The weights are in grams (g).

Soil bulk density:

ρ (g cm^{-3}) = (soil OD weight (g) – tare (g)) / 60 (cm^3)

Volumetric soil water content:

θ_v (cm^3 cm^{-3}) = θ_m x (ρ/ρ_w)

Where, ρ_w = 1 g cm^{-3} at 4 ^{o}C (density of pure water)

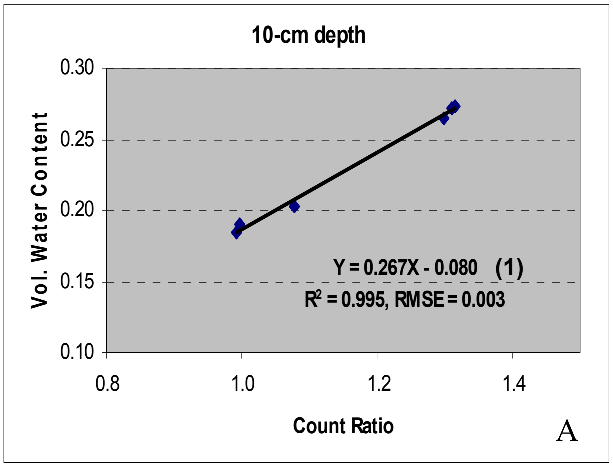
Water depth per 20-cm soil depth:

D (cm/20 cm of soil depth) = θ_v x 20 cm

In order to calculate the amount of water per volume of soil, multiply D by the surface area, which for the large lysimeter = 3 m x 3 m or 9 x 10^4 cm^2. The amount of water that is available to the plants is the total amount of water measured by the neutron probe or the lysimeter minus soil water content at what is commonly referred to as the 'wilting point'. The wilting point is the lower water availability limit at which the plant can no longer extract water from the soil and thus wilts. The upper limit is 'field capacity' or the amount of water the soil can hold with no drainage (below the depth of interest) occurring. Therefore, available water equals water content at field capacity minus water content at wilting point. Water content at the wilting point is often estimated from laboratory measurements e.g., the water remaining in the soil after a pressure of 1500 J/kg was applied to it.

Prior to digging the trench to expose the access tubes, neutron probe readings were taken with CPN 503DR at the 10-, 30-, 50-, 70-, 90-, 110-, 130-, 150-, 170-, and 190-cm soil depths. The probe assembly was set on top of the depth-control stand and a 4-minute standard reading was taken. The probe was then lowered into the access tube and a 1-minute reading was taken at each depth. The procedure was repeated for each access tube.

Volumetric soil water content was regressed against the neutron probe count ratio (CR) to obtain the calibration equation which will be used to convert CR into water content. The count ratio is the ratio of the slow neutron count at a given soil depth over the average standard count. The soil water and neutron probe data is shown in Tables 3-6 of Appendix A. Outliers and "bad" samples were discarded from the regression analysis. The correlation between water content and CR was highest for the 10-cm depth (Fig. 18A) and lowest, but still significant, for the 110- to 190-cm depth (Fig. 19D). For practical purposes, calibration equation (1) should be used for the shallow-depth reading and equation (2) for readings at or below 30 cm.



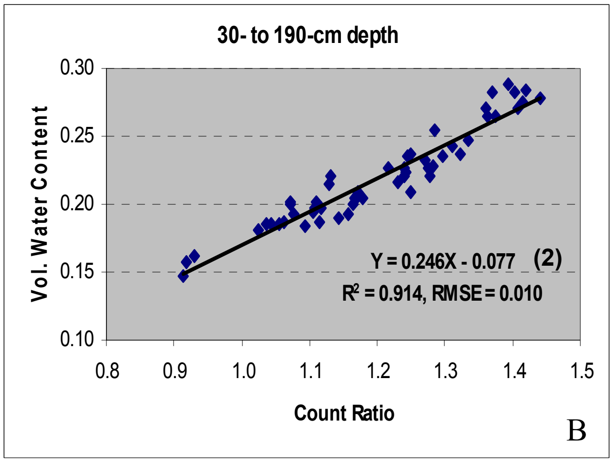


Figure 18. Volumetric soil water content (cm3/cm3) as a function of the CPN 503DR neutron probe count ratio at the (A) 10-cm and (B) 30- to 190-cm depths.

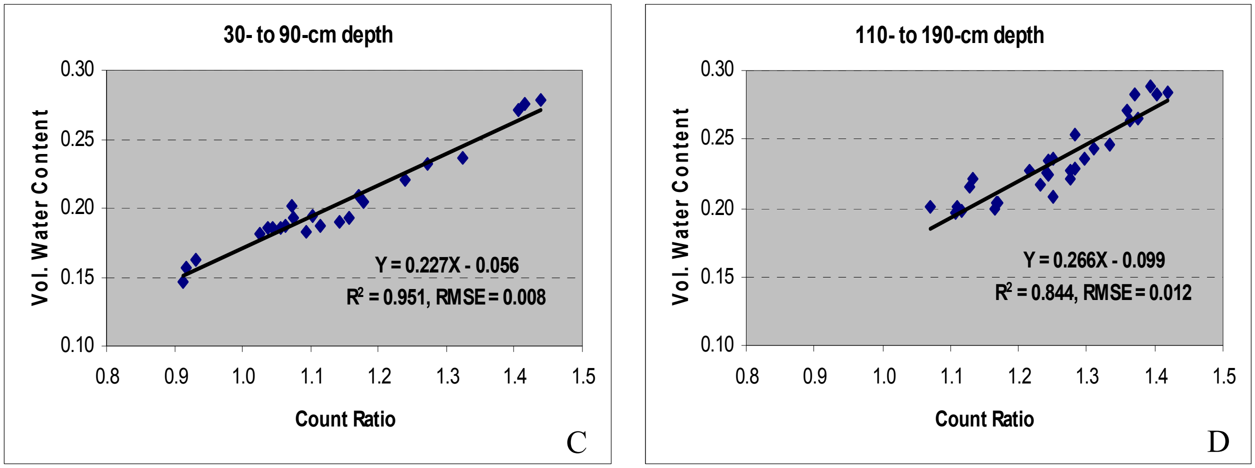


Figure 19. Volumetric soil water content (cm3/cm3) as a function of the CPN 503DR neutron probe count ratio at the (C) 30- to 90-cm and (D) 110- to 190-cm depths.

Y is volumetric soil water content in $cm^3\ cm^{-3}$ and X is count ratio. To express Y in cm of water per 20 cm of soil depth, the following equations should be used:

Upper 20 cm of soil:

Y (cm/20cm) = 5.323 X – 1.578, $R^2 = 0.995$

Lower depths:

Y (cm/20 cm) = 4.936 X – 1.541, $R^2 = 0.915$

In comparison, the calibration equation provided by CPN International, Inc. and obtained in the laboratory (Table 3) is:

Y (in/ft) = 1.984 X – 0.090 <u>or</u> Y (**cm/20cm**) = 3.307 X – 0.150, $R^2 = 1$

Table 3. CPN 503DR factory calibration (CPN International, Inc.)

Water content		1-min	Standard	Count
In/ft	cm/20cm*	Count	Count	Ratio
0	0	309	6814	0.045
4.025	6.708	14161	6828	2.074

*Converted from column 1.

The two access tubes in the lysimeter monolith were installed on October 11, 2007 using the so-called auger-from-within method. This procedure required the use of a step ladder, plywood platform, hammer, level, and a striking block. A shallow pilot hole was dug; the tube was then placed in the hole, and the Edelman auger was inserted down through the tube. Care was taken to ensure that the tube was plumb during the first 1/3 of the tube's installation. Approximately 6-inches of soil was augured and removed, followed by hammering the tube down the excavated six-inches. These two steps were repeated until the tube was set on the tank floor. The tubes were inserted to the soil tank floor. One tube was placed at 45-inches from the east wall and the other 45-inches from the west wall. Care was taken to avoid the vacuum drainage system in the bottom of the tank. The four access tubes outside the lysimeter were installed on October 23, 2007 using the same procedure for the installation of the tubes in the dry and wet sets. Each tube was aligned with a monolith centerline and placed on a bed. Each tube is situated approximately 30 feet from the north, south, east or west side of the monolith.

Neutron probe readings were taken on 1 Nov. 2007. The results are shown on Table 7 in Appendix A. We recommend that future readings be taken before and after (e.g., 48 hours after) each irrigation and at the beginning and end of each growth period. Comparison of the soil water content inside and outside the soil monolith will be used to adjust the amount of water applied to the monolith and the amount of drainage.

Soil preparation:

Shortly after the installation of the large lysimeter in 2006, the ground around it was flooded to settle the soil. Later, the ground was ripped with a Big Ox chisel plow to alleviate compaction, then plowed, disked, leveled, furrowed, and rolled. The distance between furrows is 30 inches, as is common in the Arkansas Valley. The top eight inches of the monolith were tilled with a roto-tiller and the beds and furrows were prepared with shovels and spades. There are three full beds in the middle and a half bed against the eastern and western edges of the monolith, and four furrows. They are aligned with the beds and furrows outside the monolith and run north-south.

The total area designated for the large lysimeter to ensure a good fetch is 10 acres (520 ft x 840 ft), of which 6 acres were fallowed since 2005 and an adjacent 4 acres was in alfalfa since 2003. It was paramount to get all 10 acres managed uniformly, thus in early spring 2007, the area in alfalfa was sprayed with Roundup and the whole field was planted to oats on 5 April 2007 at 140 lb/acre. The oat crop inside and outside the monolith was irrigated four times and cut for hay on 25 June 2007. Figure 20 shows the lysimeter after the oat was cut.

Figure 20. View of the lysimeter and meteorological instrumentation in late June 2007. Photo by Michael Bartolo.

The hay was baled on 2 July 2007 and the bales removed shortly after that. Oat was chosen as the first crop to be planted after the installation of the large lysimeter because it is easy to grow and could be planted and harvested early, allowing enough time for soil preparation and the seeding and establishment of the next crop (alfalfa) before fall dormancy.

In the latter part of July, the soil in the lysimeter field was again ripped, disked, and leveled. Alfalfa variety 'Genoa' was seeded on 9 August 2007 at 19 lb/acre and the field was then furrowed and rolled. The soil inside the monolith was prepared and seeded by hand. The number and arrangement of beds and furrows was the same as with the oat crop. Two hundred pounds of 11-52-0 per acre were broadcast on top of the hay crop on 6 December 2007.

Alfalfa establishment inside and outside the monolith was good to excellent, with the exception of a couple acres approximately 100 ft west of the lysimeter. In this area, alfalfa stand was spotty due to a heavy infestation of morning glory. The whole field was mowed with a brush hog on 27-28 September 2007 above the hay crop to suppress the taller weeds. That is when it became clear that approximately half of the area west of the lysimeter will have to be reseeded in the spring of 2008 to achieve a more uniform stand with the rest of the field. Alfalfa was irrigated on 17 August, 4 September, and 4 October 2007. Water from the irrigation canal was dispensed to each furrow with a siphon.

Irrigation of the soil monolith:

The monolith was irrigated each time the surrounding area was. The amount of water applied was determined by subtracting the amount that flows (flow x duration) in from the amount that flows out (tail water) of adjacent furrows, as measured by V-shaped furrow flumes. Water was pumped from the irrigation canal and applied to the monolith through a hose fitted with a flow meter and a valve. The furrows on the monolith were filled with water to simulate normal flood irrigation (Fig. 21).

Figure 21. Water being applied to the soil monolith. Photo by Michael Bartolo.

Ideally, the crop in the monolith should be irrigated the same way as the rest of the field, i.e., water flowing in and out of the furrows over the time it takes to replenish the root zone to field capacity. To do this one would have to cut slots in the section of the walls of the inner and outer tanks that stick out above ground level, to provide continuity in the furrows and water flow inside and outside the monolith. Another solution would be to pump water in and out of the furrows inside the monolith, in the same proportion as what occurs in the furrows immediately outside the monolith. Both solutions were judged impractical. Another option that was contemplated was to irrigate the lysimeter field with a linear-move sprinkler system, which would allow for uniform irrigation inside and outside the monolith. This option was put on hold due to the cost of the sprinkler system, in addition to the fact that over 90% of the crop land in the Arkansas Valley is furrow-irrigated.

Future plans:

The reference lysimeter (5 ft x 5 ft x 8 ft or 1.5 m x 1.5 m x 2.4 m) will be installed in 2008 in an adjacent field and seeded to alfalfa. The area of the large lysimeter field that has a poor alfalfa stand will be reseeded in the spring of 2008. Alfalfa in the large lysimeter field will be maintained for at least three more years to calibrate the PME. After that, the field will be planted to corn and other major crops in the Arkansas Valley (corn, wheat, sorghum, onions, etc.) to determine their crop coefficients. It will take at least two years of data per crop to generate reliable Kc estimates. Reference ET will be measured with the reference lysimeter after the results are tested and validated.

The lysimeter project is a joint effort between CWCB, DWR, and CSU. Support has also been provided by USDA-ARS engineers and scientists in Fort Collins, CO and Bushland, TX.

For more information about the lysimeter project at AVRC, please contact Lane Simmons at lane.simmons@colostate.edu or (719) 469-5559.

References:

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper No. 56. Rome, Italy.

Evett, S.R., J.A. Tolk, and T.A. Howell. 2003. A depth control stand for improved accuracy with the neutron probe. Vadoze Zone Journal 2:642-649. Soil Sci. Soc. of America, Madison, WI.

Gates, T.K., L.A. Garcia, and J.W. Labadie. 2006. Toward Optimal Water Management in Colorado's Lower Arkansas River Valley: Monitoring and Modeling to Enhance Agriculture and Environment. Colorado Water Resource Research Institute Completion Report No. 206. Colorado Agricultural Experiment Station Technical Report TR06-10, Colorado State University, Ft. Collins.

Howell, T.A., A.D. Schneider, D.A. Dusek, T.H. Marek, and J.L. Steiner. 1995. Calibration and Scale Performance of Bushland Weighing Lysimeters. Transactions of the ASCE Vol 38(4):1019-1024. American Society of Agricultural Engineers, St. Joseph, MI.

Ley, T.W. 2003. Lysimeters for Evapotranspiration Research in the Arkansas River Valley. Colorado Division of Water Resources.

Walter, I.A., R.G. Allen, R. Elliot, M.E. Jensen, D. Itenfisu, B. Mecham, T.A. Howell, R. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R.H. Cuenca, J.L. Wright, and D. Martin. 2000. ASCE'S standardized reference evapotranspiration equation. P. 209-215 *In* R.G. Evans, B. L. Benham, and T.P Trooien (ed.) National Irrigation Symposium—Proceedings of the 4th Decennial Symposium, Nov. 14-16, 2000, Phoenix, AZ. American Society of Agricultural Engineers, St. Joseph, MI.

Appendix A.

Table 1. Load cell response to the addition or removal of 9-kg weights*

Load-cell output mV/V	Weight Kg	Regression analysis	
0.20853	0	Slope	684.9324864
0.22154	9	Intercept	-142.8175164
0.23476	18	Correlation	0.999997256
0.24789	27	R-square	0.999994512
0.26098	36		
0.27412	45		
0.28727	54		
0.30042	63		
0.31350	72		
0.32668	81		
0.33980	90		
0.34003	90		
0.32695	81		
0.31367	72		
0.30065	63		
0.28741	54		
0.27426	45		
0.26112	36		
0.24799	27		
0.23474	18		
0.22185	9		
0.20853	0		

*Two 4.5 kg ammo cans or the equivalent of 1.0 mm of water on the lysimeter surface.

Table 2. Load cell response to the addition or removal of 9-kg weights when there were three (Col. 2) or six (Col. 4) 320-kg drums on top of the monolith.

(1) Load-cell output mV/V	(2) Weight Kg	(3) Load-cell Output mV/V	(4) Weight Kg	Regression analysis (Col. 1 & 2)	
1.61345	960	3.01645	1920	Slope	685.0095045
1.62685	969	3.02965	1929	Intercept	-145.5030427
1.63990	978	3.04290	1938	Correlation	0.999987745
1.65310	987	3.05610	1947	R-square	0.999975491
1.66620	996	3.06920	1956		
1.67935	1005	3.08230	1965		
1.69250	1014	3.09550	1974	Regression analysis (Col. 3 & 4)	
1.70560	1023	3.10865	1983	Slope	684.9472575
1.71880	1032	3.12180	1992	Intercept	-146.2098185
1.73195	1041	3.13495	2001	Correlation	0.999994201
1.74515	1050	3.14815	2010	R-square	0.999988403
1.74535	1050	3.14785	2010		
1.73225	1041	3.13440	2001	Average slope from Tables 1&2	
1.71910	1032	3.12165	1992		684.9630828
1.70590	1023	3.10865	1983		
1.69290	1014	3.09570	1974		
1.67980	1005	3.08225	1965		
1.66655	996	3.06900	1956		
1.65350	987	3.05605	1947		
1.64040	978	3.04300	1938		
1.62725	969	3.02970	1929		
1.61410	960	3.01660	1920		

Table 3. Neutron probe field calibration—Soil data for the 'dry' set.

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
A	1	10	64.7	77.2	134.9	0.100	1.170	0.117
A	2	10	65.8	82.2	141.7	0.083	1.265	0.105
A	3	10	65.1	110.5	160.3	0.161	1.587	0.255
A	4	10	64.4	110.3	159.4	0.161	1.583	0.255
A	1	30	64.4	114.3	163.1	0.158	1.645	0.260
A	2	30	65.0	105.7	156.0	0.162	1.517	0.245
A	3	30	65.5	109.5	161.3	0.143	1.597	0.228
A	4	30	64.1	98.4	149.8	0.148	1.428	0.212
A	1	50	64.7	107.6	158.9	0.142	1.570	0.223
A	2	50	80.5	109.7	175.9	0.150	1.590	0.238
A	3	50	65.8	99.8	155.6	0.111	1.497	0.167
A	4	50	64.8	99.5	154.3	0.112	1.492	0.167
A	1	70	65.1	94.2	149.9	0.111	1.413	0.157
A	2	70	65.2	90.4	146.8	0.108	1.360	0.147
A	3	70	65.1	94.7	150.4	0.110	1.422	0.157
A	4	70	65.7	93.9	149.6	0.119	1.398	0.167
A	1	90	65.1	93.1	147.9	0.124	1.380	0.172
A	2	90	65.5	93.8	148.6	0.129	1.385	0.178
A	3	90	64.7	94.2	148.1	0.129	1.390	0.180
A	4	90	65.1	93.6	147.1	0.141	1.367	0.193
A	1	110	68.7	91.6	150.8	0.116	1.368	0.158
A	2	110	65.1	94.1	146.7	0.153	1.360	0.208
A	3	110	74.5	96.0	159.7	0.127	1.420	0.180
A	4	110	64.6	95.6	147.5	0.153	1.382	0.212
A	1	130	65.4	97.6	151.1	0.139	1.428	0.198
A	2	130	65.4	100.3	154.1	0.131	1.478	0.193
A	3	130	65.3	100.1	153.3	0.138	1.467	0.202
A	4	130	65.5	100.1	153.0	0.144	1.458	0.210
A	1	150	65.6	98.1	152.5	0.129	1.448	0.187
A	2	150	64.9	102.3	155.0	0.135	1.502	0.203
A	3	150	65.5	100.8	153.0	0.152	1.458	0.222
A	4	150	65.4	98.8	151.9	0.142	1.442	0.205
A	1	170	71.4	96.0	153.3	0.172	1.365	0.235
A	2	170	64.8	94.9	147.0	0.155	1.370	0.212
A	3	170	69.8	93.7	149.5	0.176	1.328	0.233
A	4	170	65.0	98.0	147.5	0.188	1.375	0.258
A	1	190	65.4	100.1	149.1	0.196	1.395	0.273
A	2	190	64.4	98.8	147.6	0.188	1.387	0.260
A	3	190	73.6	98.1	156.1	0.189	1.375	0.260
A	4	190	74.4	101.6	158.6	0.207	1.403	0.290
B	1	10	65.5	81.9	139.2	0.111	1.228	0.137
B	2	10	84.8	74.8	153.2	0.094	1.140	0.107
B	3	10	64.6	109.3	159.3	0.154	1.578	0.243

Table 3 (Continued)

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
B	4	10	64.4	111.2	160.4	0.158	1.600	0.253
B	1	30	65.3	108.0	159.3	0.149	1.567	0.233
B	2	30	65.3	108.7	159.9	0.149	1.577	0.235
B	3	30	65.4	107.8	159.5	0.146	1.568	0.228
B	4	30	65.0	107.1	158.3	0.148	1.555	0.230
B	1	50	65.4	104.8	157.5	0.138	1.535	0.212
B	2	50	64.9	104.5	156.1	0.146	1.520	0.222
B	3	50	65.4	100.7	155.6	0.116	1.503	0.175
B	4	50	69.8	103.8	161.6	0.131	1.530	0.200
B	1	70	65.6	91.9	148.4	0.110	1.380	0.152
B	2	70	65.5	93.2	150.3	0.099	1.413	0.140
B	3	70	65.1	91.8	147.8	0.110	1.378	0.152
B	4	70	65.5	89.3	146.1	0.108	1.343	0.145
B	1	90	64.9	90.7	144.9	0.134	1.333	0.178
B	2	90	64.8	96.0	149.4	0.135	1.410	0.190
B	3	90	84.2	89.1	163.1	0.129	1.315	0.170
B	4	90	64.9	95.6	148.2	0.148	1.388	0.205
B	1	110	65.4	66.2	122.7	0.155	0.955	0.148
B	2	110	64.2	98.6	149.5	0.156	1.422	0.222
B	3	110	64.6	97.5	148.9	0.157	1.405	0.220
B	4	110	65.2	96.2	148.2	0.159	1.383	0.220
B	1	130	84.1	98.1	170.8	0.131	1.445	0.190
B	2	130	65.6	95.8	150.2	0.132	1.410	0.187
B	3	130	65.6	87.3	142.1	0.141	1.275	0.180
B	4	130	65.7	99.1	152.4	0.143	1.445	0.207
B	1	150	64.6	102.1	155.0	0.129	1.507	0.195
B	2	150	64.9	103.4	156.2	0.133	1.522	0.202
B	3	150	64.9	100.4	153.2	0.137	1.472	0.202
B	4	150	80.9	96.2	165.0	0.144	1.402	0.202
B	1	170	64.1	99.8	149.5	0.169	1.423	0.240
B	2	170	65.8	93.2	145.3	0.172	1.325	0.228
B	3	170	64.7	100.5	149.5	0.185	1.413	0.262
B	4	170	65.0	101.6	152.0	0.168	1.450	0.243
B	1	190	65.2	103.4	151.7	0.195	1.442	0.282
B	2	190	64.3	101.1	147.8	0.211	1.392	0.293
B	3	190	64.5	102.2	148.9	0.211	1.407	0.297
B	4	190	72.0	97.9	153.1	0.207	1.352	0.280
C	1	10	64.0	89.9	146.5	0.090	1.375	0.123
C	2	10	65.3	83.3	141.8	0.089	1.275	0.113
C	3	10	64.5	114.7	163.5	0.159	1.650	0.262
C	4	10	64.2	116.0	164.5	0.157	1.672	0.262
C	1	30	65.7	110.1	161.7	0.147	1.600	0.235
C	2	30	65.3	106.4	157.9	0.149	1.543	0.230

Table 3 (Continued)

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
C	3	30	65.1	99.8	152.7	0.139	1.460	0.203
C	4	30	65.5	99.4	152.0	0.149	1.442	0.215
C	1	50	64.8	103.7	155.9	0.138	1.518	0.210
C	2	50	65.2	102.1	154.7	0.141	1.492	0.210
C	3	50	80.5	99.1	169.4	0.115	1.482	0.170
C	4	50	64.8	100.0	154.1	0.120	1.488	0.178
C	1	70	65.1	93.9	149.5	0.113	1.407	0.158
C	2	70	73.0	92.7	156.1	0.116	1.385	0.160
C	3	70	64.9	94.0	148.9	0.119	1.400	0.167
C	4	70	64.9	95.1	150.3	0.114	1.423	0.162
C	1	90	77.4	97.1	162.7	0.138	1.422	0.197
C	2	90	64.8	94.7	148.6	0.130	1.397	0.182
C	3	90	65.7	95.8	149.7	0.140	1.400	0.197
C	4	90	76.3	92.4	156.9	0.146	1.343	0.197
C	1	110	70.5	94.3	153.0	0.143	1.375	0.197
C	2	110	65.2	96.3	149.0	0.149	1.397	0.208
C	3	110	72.9	90.3	150.4	0.165	1.292	0.213
C	4	110	75.6	96.1	158.1	0.165	1.375	0.227
C	1	130	73.7	90.5	153.2	0.138	1.325	0.183
C	2	130	64.9	94.5	147.5	0.144	1.377	0.198
C	3	130	70.4	92.6	151.3	0.145	1.348	0.195
C	4	130	64.9	99.2	151.4	0.147	1.442	0.212
C	1	150	64.6	99.3	152.5	0.130	1.465	0.190
C	2	150	65.1	96.9	150.1	0.140	1.417	0.198
C	3	150	84.8	101.7	173.7	0.144	1.482	0.213
C	4	150	65.1	98.9	151.2	0.149	1.435	0.213
C	1	170	77.0	100.4	162.7	0.172	1.428	0.245
C	2	170	75.6	94.7	156.1	0.176	1.342	0.237
C	3	170	64.6	100.5	148.9	0.192	1.405	0.270
C	4	170	84.3	96.7	165.2	0.195	1.348	0.263
C	1	190	64.9	98.4	146.0	0.213	1.352	0.288
C	2	190	65.5	94.5	143.8	0.207	1.305	0.270
C	3	190	65.6	101.9	150.2	0.204	1.410	0.288
C	4	190	65.2	90.8	140.3	0.209	1.252	0.262

cc is cm^3

Comment: The shaded numbers were not included in the calibration due to “problems” with the corresponding soil samples e.g., incomplete sample.

Table 4. Neutron probe field calibration—Soil data for the 'wet' set.

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
D	1	10	70.4	94.2	150.0	0.183	1.327	0.243
D	2	10	64.7	87.7	139.1	0.179	1.240	0.222
D	3	10	65.1	116.8	163.4	0.188	1.638	0.308
D	4	10	64.9	111.2	159.0	0.182	1.568	0.285
D	1	30	64.3	110.4	157.2	0.188	1.548	0.292
D	2	30	65.1	114.1	161.0	0.190	1.598	0.303
D	3	30	85.4	98.5	169.3	0.174	1.398	0.243
D	4	30	64.6	104.1	152.2	0.188	1.460	0.275
D	1	50	65.5	98.6	151.2	0.151	1.428	0.215
D	2	50	64.1	98.6	150.5	0.141	1.440	0.203
D	3	50	65.5	94.9	148.6	0.142	1.385	0.197
D	4	50	65.1	91.6	144.7	0.151	1.327	0.200
D	1	70	65.6	94.0	148.9	0.128	1.388	0.178
D	2	70	74.0	95.3	157.8	0.137	1.397	0.192
D	3	70	65.3	91.6	146.0	0.135	1.345	0.182
D	4	70	65.2	92.6	146.9	0.133	1.362	0.182
D	1	90	65.6	94.2	148.4	0.138	1.380	0.190
D	2	90	64.6	95.7	148.8	0.137	1.403	0.192
D	3	90	73.0	94.4	156.1	0.136	1.385	0.188
D	4	90	84.6	95.5	168.6	0.137	1.400	0.192
D	1	110	64.4	97.5	150.2	0.136	1.430	0.195
D	2	110	68.0	95.7	152.5	0.133	1.408	0.187
D	3	110	64.7	96.8	147.5	0.169	1.380	0.233
D	4	110	74.4	77.7	141.7	0.155	1.122	0.173
D	1	130	64.2	101.1	152.1	0.150	1.465	0.220
D	2	130	65.4	100.3	149.5	0.193	1.402	0.270
D	3	130	64.5	101.2	152.3	0.153	1.463	0.223
D	4	130	75.6	80.2	144.9	0.157	1.155	0.182
D	1	150	72.0	98.0	156.3	0.163	1.405	0.228
D	2	150	73.6	70.5	135.2	0.144	1.027	0.148
D	3	150	71.4	94.4	152.5	0.164	1.352	0.222
D	4	150	65.2	97.9	149.3	0.164	1.402	0.230
D	1	170	64.5	102.2	151.1	0.180	1.443	0.260
D	2	170	65.3	98.3	148.1	0.187	1.380	0.258
D	3	170	73.8	90.7	150.5	0.183	1.278	0.233
D	4	170	84.2	92.3	162.4	0.180	1.303	0.235
D	1	190	64.4	86.7	138.1	0.176	1.228	0.217
D	2	190	84.3	86.8	158.0	0.178	1.228	0.218
D	3	190	65.1	101.1	149.2	0.202	1.402	0.283
D	4	190	77.0	100.9	160.9	0.203	1.398	0.283
E	1	10	74.5	91.6	151.6	0.188	1.285	0.242
E	2	10	77.4	95.5	157.9	0.186	1.342	0.250

Table 4 (Continued)

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
E	3	10	73.7	114.3	170.0	0.187	1.605	0.300
E	4	10	70.5	107.7	160.5	0.197	1.500	0.295
E	1	30	65.5	110.0	158.6	0.182	1.552	0.282
E	2	30	64.7	107.7	155.9	0.181	1.520	0.275
E	3	30	72.9	106.8	164.2	0.170	1.522	0.258
E	4	30	76.3	108.9	169.0	0.175	1.545	0.270
E	1	50	65.8	98.9	152.4	0.142	1.443	0.205
E	2	50	64.9	99.5	151.8	0.145	1.448	0.210
E	3	50	75.6	99.3	163.5	0.130	1.465	0.190
E	4	50	65.2	93.3	146.0	0.155	1.347	0.208
E	1	70	65.4	92.6	146.6	0.140	1.353	0.190
E	2	70	65.6	95.8	149.8	0.138	1.403	0.193
E	3	70	65.0	64.4	121.6	0.138	0.943	0.130
E	4	70	64.6	100.9	153.5	0.135	1.482	0.200
E	1	90	85.4	94.8	169.0	0.134	1.393	0.187
E	2	90	64.8	97.6	150.9	0.134	1.435	0.192
E	3	90	64.9	96.7	149.2	0.147	1.405	0.207
E	4	90	64.9	98.8	152.6	0.127	1.462	0.185
E	1	110	65.2	85.0	137.7	0.172	1.208	0.208
E	2	110	65.4	99.9	150.6	0.173	1.420	0.245
E	3	110	64.1	98.4	148.9	0.160	1.413	0.227
E	4	110	65.0	96.3	151.1	0.118	1.435	0.170
E	1	130	65.7	100.2	152.0	0.161	1.438	0.232
E	2	130	84.8	82.0	154.7	0.173	1.165	0.202
E	3	130	64.7	101.6	153.0	0.151	1.472	0.222
E	4	130	65.5	102.1	153.7	0.158	1.470	0.232
E	1	150	64.2	94.7	145.6	0.163	1.357	0.222
E	2	150	64.9	105.6	155.4	0.167	1.508	0.252
E	3	150	64.0	100.8	150.4	0.167	1.440	0.240
E	4	150	65.8	101.2	153.2	0.158	1.457	0.230
E	1	170	64.6	93.4	143.0	0.191	1.307	0.250
E	2	170	68.7	98.7	151.9	0.186	1.387	0.258
E	3	170	84.8	100.3	168.5	0.198	1.395	0.277
E	4	170	65.4	100.2	149.3	0.194	1.398	0.272
E	1	190	84.1	101.9	169.3	0.196	1.420	0.278
E	2	190	64.6	99.9	147.7	0.202	1.385	0.280
E	3	190	65.7	101.0	149.9	0.200	1.403	0.280
E	4	190	65.0	102.9	150.5	0.204	1.425	0.290
F	1	10	65.7	93.3	144.3	0.187	1.310	0.245
F	2	10	65.1	93.0	142.8	0.197	1.295	0.255
F	3	10	65.2	110.5	158.2	0.188	1.550	0.292
F	4	10	65.1	111.3	158.4	0.193	1.555	0.300
F	1	30	65.8	110.1	159.0	0.181	1.553	0.282

Table 4 (Continued)

Access Tube	Sample No.	Depth (cm)	Tare (g)	Fresh Weight Net (g)	O.D. Weight w/tare (g)	Water Content (g/g)	Bulk Density (g/cc)	Water Content (cc/cc)
F	2	30	80.5	108.7	172.5	0.182	1.533	0.278
F	3	30	64.9	109.2	158.1	0.172	1.553	0.267
F	4	30	65.5	110.8	159.8	0.175	1.572	0.275
F	1	50	65.1	99.1	151.6	0.146	1.442	0.210
F	2	50	65.4	96.3	148.6	0.157	1.387	0.218
F	3	50	65.8	96.2	149.8	0.145	1.400	0.203
F	4	50	65.6	93.0	146.5	0.150	1.348	0.202
F	1	70	65.7	98.8	153.3	0.128	1.460	0.187
F	2	70	65.4	94.2	148.3	0.136	1.382	0.188
F	3	70	64.6	83.2	138.2	0.130	1.227	0.160
F	4	70	65.2	97.3	151.3	0.130	1.435	0.187
F	1	90	65.1	99.4	153.8	0.121	1.478	0.178
F	2	90	65.4	93.5	148.4	0.127	1.383	0.175
F	3	90	64.2	99.1	151.9	0.130	1.462	0.190
F	4	90	64.6	103.1	155.6	0.133	1.517	0.202
F	1	110	65.6	90.6	143.6	0.162	1.300	0.210
F	2	110	64.8	94.4	145.6	0.168	1.347	0.227
F	3	110	64.9	101.2	151.8	0.165	1.448	0.238
F	4	110	65.0	81.1	134.4	0.169	1.157	0.195
F	1	130	65.5	95.8	146.7	0.180	1.353	0.243
F	2	130	64.8	69.5	123.3	0.188	0.975	0.183
F	3	130	64.4	87.0	139.9	0.152	1.258	0.192
F	4	130	65.3	102.5	154.2	0.153	1.482	0.227
F	1	150	65.3	94.9	148.2	0.145	1.382	0.200
F	2	150	64.8	107.6	157.8	0.157	1.550	0.243
F	3	150	64.9	102.5	153.9	0.152	1.483	0.225
F	4	150	69.8	98.8	156.7	0.137	1.448	0.198
F	1	170	64.9	100.0	150.6	0.167	1.428	0.238
F	2	170	65.3	105.5	156.8	0.153	1.525	0.233
F	3	170	80.9	93.5	160.9	0.169	1.333	0.225
F	4	170	64.6	105.9	155.6	0.164	1.517	0.248
F	1	190	65.8	83.7	137.2	0.172	1.190	0.205
F	2	190	64.9	84.3	136.6	0.176	1.195	0.210
F	3	190	64.9	101.4	149.9	0.193	1.417	0.273
F	4	190	65.1	102.1	150.9	0.190	1.430	0.272

cc is cm^3

Comment: The shaded numbers were not included in the calibration due to “problems” with the corresponding soil samples e.g., incomplete sample.

Table 5. Neutron probe field calibration readings/counts.

4-minute standard counts						
Tubes A&B	6603	6606	NA	Tube D	6603	6601
Tube C	6633	6552	6561	Tube E	6635	6564
				Tube F	6652	6624
Access Tube	**Depth (cm)**	**1-min Count[1]**	**Count Ratio[2]**	**Access Tube**	**1-min Count[1]**	**Count Ratio[2]**
A	10	7121	1.078	D	8567	1.298
A	30	8743	1.324	D	9508	1.440
A	50	6971	1.055	D	7780	1.178
A	70	6057	0.917	D	7219	1.093
A	90	6770	1.025	D	7544	1.143
A	110	7076	1.071	D	8250	1.250
A	130	7328	1.109	D	8208	1.243
A	150	7707	1.167	D	8427	1.276
A	170	8215	1.244	D	8808	1.334
A	190	8982	1.360	D	9376	1.420
B	10	6550	0.992	E	8650	1.311
B	30	8397	1.271	E	9283	1.407
B	50	7080	1.072	E	7736	1.172
B	70	6033	0.913	E	7287	1.104
B	90	6898	1.044	E	7643	1.158
B	110	7476	1.132	E	8020	1.215
B	130	7317	1.108	E	8462	1.282
B	150	7692	1.165	E	8558	1.297
B	170	8661	1.311	E	9001	1.364
B	190	9205	1.394	E	9261	1.403
C	10	6555	0.996	F	8735	1.316
C	30	8155	1.239	F	9390	1.415
C	50	6822	1.036	F	7769	1.170
C	70	6127	0.931	F	7057	1.063
C	90	7079	1.076	F	7393	1.114
C	110	7422	1.128	F	8237	1.241
C	130	7347	1.116	F	8477	1.277
C	150	7701	1.170	F	8173	1.231
C	170	8451	1.284	F	8295	1.250
C	190	9019	1.370	F	9126	1.375

[1]Average of two readings

[2]One-minute count/Average standard count

Table 6. Average soil moisture and count ratios used to calibrate the neutron probe CPN 503DR at the Arkansas Valley Research Center.

Access Tube	Depth (cm)	Water Content (g/g)	Bulk density (g/cc)	Water content (cc/cc)	Count Ratio
A	10	0.140	1.447	0.203	1.078
A	30	0.153	1.547	0.236	1.324
A	50	0.122	1.519	0.185	1.055
A	70	0.112	1.398	0.157	0.917
A	90	0.131	1.380	0.181	1.025
A	110	0.144	1.387	0.200	1.071
A	130	0.138	1.458	0.201	1.109
A	150	0.140	1.463	0.204	1.167
A	170	0.173	1.360	0.235	1.244
A	190	0.195	1.390	0.271	1.360
B	10	0.129	1.387	0.185	0.992
B	30	0.148	1.567	0.232	1.271
B	50	0.133	1.522	0.202	1.072
B	70	0.107	1.379	0.147	0.913
B	90	0.136	1.362	0.186	1.044
B	110	0.157	1.403	0.221	1.132
B	130	0.137	1.433	0.196	1.108
B	150	0.136	1.475	0.200	1.165
B	170	0.173	1.403	0.243	1.311
B	190	0.206	1.398	0.288	1.394
C	10	0.123	1.493	0.190	0.996
C	30	0.146	1.511	0.221	1.239
C	50	0.124	1.496	0.186	1.036
C	70	0.115	1.404	0.162	0.931
C	90	0.139	1.390	0.193	1.076
C	110	0.156	1.382	0.215	1.128
C	130	0.143	1.373	0.197	1.116
C	150	0.141	1.450	0.204	1.170
C	170	0.184	1.381	0.254	1.284
C	190	0.208	1.356	0.283	1.370
D	10	0.183	1.443	0.265	1.298
D	30	0.185	1.501	0.278	1.440
D	50	0.146	1.395	0.204	1.178
D	70	0.134	1.373	0.183	1.093
D	90	0.137	1.392	0.190	1.143
D	110	0.148	1.406	0.208	1.250
D	130	0.153	1.371	0.224	1.243
D	150	0.164	1.386	0.227	1.276
D	170	0.183	1.351	0.247	1.334
D	190	0.202	1.400	0.283	1.420

cc is cm^3

Table 6 (Continued)

Access Tube	Depth (cm)	Water Content (g/g)	Bulk density (g/cc)	Water content (cc/cc)	Count Ratio
A	10	0.140	1.447	0.203	1.078
E	10	0.189	1.433	0.272	1.311
E	30	0.177	1.535	0.271	1.407
E	50	0.147	1.413	0.208	1.172
E	70	0.138	1.413	0.195	1.104
E	90	0.135	1.424	0.193	1.158
E	110	0.168	1.347	0.227	1.215
E	130	0.156	1.460	0.228	1.282
E	150	0.164	1.440	0.236	1.297
E	170	0.193	1.372	0.264	1.364
E	190	0.200	1.408	0.282	1.403
F	10	0.191	1.428	0.273	1.316
F	30	0.177	1.553	0.275	1.415
F	50	0.149	1.394	0.208	1.170
F	70	0.131	1.426	0.187	1.063
F	90	0.128	1.460	0.186	1.114
F	110	0.166	1.365	0.226	1.241
F	130	0.162	1.364	0.221	1.277
F	150	0.148	1.466	0.217	1.231
F	170	0.163	1.451	0.236	1.250
F	190	0.186	1.423	0.265	1.375

cc is cm^3

Table 7. Large lysimeter neutron probe readings on November 1, 2007.

	Monolith West		Monolith East		Exterior North		Exterior East		Exterior South		Exterior West	
Depth	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**	**Count**	**Volume**
STD	6595	n/a	6601	n/a	6619	n/a	6616	n/a	6634	n/a	6620	n/a
10cm	5812	15.57%	5437	14.03%	6184	16.98%	6336	17.60%	5964	16.04%	6701	19.06%
30cm	8577	24.39%	8571	24.34%	7340	19.66%	8203	22.89%	8497	23.90%	7924	21.83%
50cm	6507	16.64%	6253	15.67%	6844	17.81%	6608	16.94%	7011	18.37%	6598	16.89%
70cm	6516	16.67%	6131	15.21%	6854	17.85%	6456	16.37%	7247	19.25%	6417	16.21%
90cm	7150	19.05%	7205	19.23%	7237	19.28%	7024	18.49%	7124	18.79%	6519	16.59%
110cm	8326	23.45%	8549	24.26%	7586	20.58%	7486	20.22%	7036	18.47%	7058	18.60%
130cm	8921	25.68%	8702	24.83%	8058	22.34%	7826	21.49%	7652	20.76%	7070	18.65%
150cm	8949	25.78%	9005	25.96%	8159	22.71%	7916	21.82%	8268	23.05%	7568	20.51%
170cm	9117	26.41%	9294	27.04%	7918	21.82%	7877	21.68%	8294	23.15%	7989	22.08%
190cm	9557	28.06%	9446	27.61%	7891	21.71%	8387	23.58%	8661	24.51%	7948	21.92%