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Comparison of ET Measured with Neutron Moisture Meters and Weighing Lysimeters

James L. Wright[1]

Abstract

The neutron moisture meter (N.M.) method of determining crop water use is frequently used in research and irrigated agriculture. This study was conducted to compare crop evapotranspiration (ET) estimated by the N.M. method with ET measured with a weighing lysimeter. Neutron meter data were obtained in a furrow-irrigated field of alfalfa (Medicago sativa L.) equipped with a weighing lysimeter and in alfalfa plots irrigated with a line-source sprinkler system. Seasonal ET estimated from the N.M. data for the furrow irrigation treatment was 15% less than lysimeter ET when only a 2-m soil profile was considered, and was 10% less than lysimeter ET for a 3-m profile. The seasonal ET estimated from N.M. data for the sprinkler treatment with a dry subsoil layer was within 2.5% of lysimeter ET. The N.M. method lacked capability of measuring root extraction of water from the relatively wet, lower soil layers which existed with furrow irrigation.

Introduction

The neutron moisture meter, or the neutron probe as it is often called, provides a useful method of monitoring soil-water contents utilizing vertically installed access tubes within the root zone of a crop (Visvalingam & Tandy 1972). Temporal changes of measured soil-water contents can in turn be used to estimate the water use of crops under field conditions. Periodic neutron meter measurements at selected sites within an irrigated field are now often used to provide important feedback data for a climatic-based irrigation scheduling scheme (Jensen & Wright 1978) or for irrigation scheduling schemes which rely principally on soil-water data (Campbell & Campbell 1982). The neutron meter method is used extensively in irrigation research, such as that of Retta & Hanks (1980), where variable irrigation treatments are used to permit developing crop growth and yield relationships as a function of crop water use.

While the neutron meter is useful for monitoring soil water contents, the reliability of resulting crop water-use estimates is limited because the neutron meter provides only an indirect measure of the average soil water content of a volume of soil surrounding the access tube. Errors due to this inherent problem are reduced with proper adherence to calibration and other operational procedures (Haverkamp et al. 1984; Schmugge et al. 1980; and Visvalingam & Tandy 1972.) Additionally, crop water use

[1]Soil Scientist, Soil and Water Management Research Unit, USDA-Agricultural Research Service, 3793 N 3600 E, Kimberly, ID 83341.

estimates obtained from neutron meter measurements are subject to the same errors that may occur in the calculation of the soil-water balance from any soil-water content data. Particularly troublesome are the errors associated with vertical and lateral water movement in the time interval between measurements.

Weighing lysimeters, which provide a direct measure of crop ET, are increasingly being used in research to determine crop water requirements and in the development of crop coefficients and other relationships for improved irrigation management. The study reported herein compares the water-use by alfalfa as estimated from neutron meter data, for furrow and sprinkler irrigation treatments, with lysimeter alfalfa ET independently measured with a weighing lysimeter to provide an evaluation of the reliability of the neutron meter method in determining water use by deep-rooted crops.

Field Studies

Research was conducted at the USDA Agricultural Research Service experimental farm about 1 km east of Kimberly, Idaho. The soil classified as Portneuf silt loam was about 4 m deep underlain by basalt bedrock. Local canal water diverted from the Snake River, classified as low salinity water, was used for irrigation.

Neutron meter data were obtained in furrow irrigation trials during 1981 at a site near a weighing lysimeter located in a 2.6-ha field planted to alfalfa in April of the previous year. Irrigation furrows were spaced at 0.76-m intervals and the field slope was about 0.5%. Irrigations were usually about 24 h in duration. A set of three aluminum access tubes was installed to a depth of 3.6 m about 1.5 m apart, in the cross slope direction, 15 m from the lysimeter. Basalt bedrock was encountered at about 3.5 m with one of the tubes. Neutron meter measurements were obtained periodically throughout the growing season including a few days before and after each irrigation. The alfalfa was harvested three times during the study by swathing and baling.

The soil bin of the weighing lysimeter was 1.83 m square by 1.22 m deep and rested on a mechanical platform scale (see Wright, 1988, for details on the lysimeter and field site). During field irrigation, water was pumped onto the lysimeter surface from an adjoining furrow sufficiently to replenish the previous depletion of soil water. Lysimeter forage was manually harvested within a day or two of field harvest.

The sprinkler-irrigated trial was conducted at a site about 1 km away from the lysimeter field during 1983. Data were collected as part of a line-source experiment with alfalfa [see Hill et al. (1985) for further details]. The alfalfa crop was in its fourth year at the site and had been allowed during previous years to deplete most of the available soil water from the 2- to 3-m zone of the soil profile. The "dry sublayer" thus created permitted definition of boundary conditions in the lower root zone. Sprinkler irrigations applied at nearly weekly intervals were measured at the access tube with a 10-cm diameter rain gage. Irrigations were scheduled to apply sufficient water to maintain adequate soil-water in the upper 1.5 m of the soil profile for near maximum alfalfa growth, but to prevent drainage of water downward into the dry sublayer. Alfalfa was harvested three times during the season with a small forage plot harvester. Alfalfa ET data were independently measured with a lysimeter located in a 2.2-ha field immediately adjacent to the site of the lysimeter used in the furrow irrigation trials.

Neutron meter measurements were made with a Troxler Model 105A Depth Moisture Gauge (Disclaimer: Names of equipment manufacturers do not imply endorsement by the U.S. Department of Agriculture). The neutron meter was specifically calibrated for the study sites using 3-m aluminum access tubes installed at wet and dry sites. A series of ten 30-s shield counts were obtained on the tailgate of a pick-up truck before and after reading the access tubes. A series of five 30-s counts were then taken at 15.2-cm depth intervals beginning at 15 cm. Immediately following the neutron readings, three 3.175 cm dia. soil cores were taken at a radius of 15 cm around the access tubes with a tractor-mounted soil sampler to the depth of the access tube. The soil cores were sectioned into 15.2 cm long samples for which the volumetric water content was determined using usual gravimetric procedures and the known volume of the sample. The bulk density of each sample section was calculated and used to ascertain the reliability of the sample, but the bulk density was not used directly in developing calibration equations. Calibration equations were developed by linear regression of the measured volumetric water content and the corresponding neutron meter count ratios. Equations were developed for three distinct zones of the soil profile: 0 to 0.5 m, 0.5 to 1.0 m, and 1.0 to 3.0 m. A correction factor was also estimated for the 15-cm depth readings. The use of the three distinct equations provided better accuracy in determining the actual soil-water profile, as compared with using a single equation based on the combined data, but had a lesser effect on the accuracy of calculated temporal changes in water content. Neutron meter readings at the study sites were obtained as a series of single 30-s readings at successive depths. Five 30-s shield counts were taken before and after reading each set of access tubes. Count ratios calculated from the mean shield count were used to calculate the volumetric water content.

For the furrow irrigation trials, a 3-m long horizontal platform, constructed from a section of an aluminum extension ladder, with 50-cm legs was placed near the access tubes during readings to permit the neutron meter operator to approach the access tubes without trampling the crop. The platform was not used for the sprinkler trials but access trails were established so that the operator could approach the access tube using designated stepping points. Little visible damage resulted within a 1-m radius of the tube.

Crop water use as ET was calculated from the soil-water content measurements obtained from the neutron meter readings using usual soil-water balance procedures where ET for the given time period was the sum of soil water depletion (positive depletion is a negative change in water content), calculated from the change in volumetric soil water content, plus irrigation, plus rainfall, and minus drainage from the root zone.

Results and Discussion

Soil conditions at the furrow irrigation site were well within the upper portions of available soil water as indicated by two representative soil-water profiles in Fig. 1. Data points for the 7/07-profile, day of year (DOY) 188 and the 7/10-profile show the respective depths at which neutron meter readings were obtained in this study. Plotted data points are means for the three access tubes. Profiles representing the drained upper limit (DUL) and the lower limit of available water (LLA) are also plotted in Fig. 1 for reference [see Ratliff et al. (1983) for complete definitions of these terms]. The DUL data were developed for the field site from soil-water profiles obtained with a neutron meter in tests where the soil was amply wetted, covered to prevent evaporation, and allowed to drain until drainage was negligible. The LLA data were obtained from trials when established alfalfa was allowed to deplete available soil water from the root zone. The soil profile below 0.5 m was essentially at the DUL when neutron meter readings were initiated on DOY 082 (23 March). The alfalfa was then still dormant from winter time, but the soil had not been frozen for several weeks. Alfalfa began significant growth about DOY 105.

Data for the 7/07-profile, shown in Fig. 1, were obtained a few hours before an irrigation commenced. The 7/10-profile was intentionally obtained only two days after irrigation ceased to provide information on the downward movement of applied water. As shown, prior to irrigation soil water contents were less than the DUL profile to a depth of 0.6 m, while after irrigation soil-water contents were higher than the DUL-profile to the 2.4-m depth because of the relatively slow drainage characteristics of the soil.

Data pertaining to the soil-water balance and estimated ET for the furrow irrigation trial are summarized in Table 1. Listed profile water contents are averages for the three access tubes. The 0- to 2.4-m and 2.4- to 3.0-m zones were listed separately to show the change in lower portions of the profile relative to those in upper portions. For reference to the DUL-profile of Fig. 1, if the entire soil profile on DOY 082 had been at the DUL level, the profile water contents would have been 0.283 and 0.354 m^3 m^{-3} for the 0- to 2.4-m and 2.4- to 3.0-m profiles, respectively. Water contents varied with time in the upper profile in response to irrigation, root extraction of water, and drainage into lower soil layers. Water contents in the lower zone were less cyclical, generally, above DUL levels and actually showed a gradual increase until DOY 239 when irrigations ceased after which they gradually declined. Even though 57 days elapsed from the final irrigation until the final neutron readings, final soil water contents were about equal to the initial ones of DOY 082 (see Table 1). The increase in water content in the lower zone lagged behind irrigations by more than 7 days in several cases, as can be seen by comparing water contents for DOY's 142 and 154 following the irrigation on DOY 135. This indicates relatively slow downward movement of water into the lower profile.

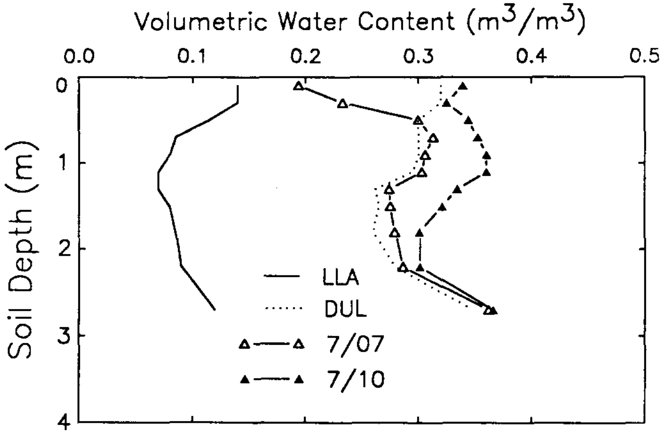

Figure 1. Soil-water content profiles for furrow-irrigated alfalfa.

Table 1. Summary data for furrow irrigated alfalfa where ET was estimated from soil-water contents measured throughout the growing season with a neutron moisture meter (N.M.) and alfalfa ET was also measured with a weighing lysimeter (Lys.), Kimberly, ID.

	Profile water content		Cumulative depletion		Cumulative data		
Day of year (DOY)	0 m to 2.4 m	2.4 m to 3.0 m	0 m to 2.4 m	2.4 m to 3.0 m	Irr. and rain	N.M. ET	Lys. ET
	$m^3\ m^{-3}$		mm				
082	.275	.347	0	0	0	0	0
113	.273	.348	5	-1	39	43	85
131	.249	.347	61	-1	50	110	170
142[I]	.302	.335	-66	-2	233	165	211
154	.283	.355	-19	-6	235	210	277
160[I]	.324	.362	-119	-9	373	245	308
188	.270	.358	12	-7	373	378	466
191[I]	.325	.360	-122	-8	525	395	487
210	.278	.362	-8	-9	525	508	593
217[I]	.315	.357	-96	-6	650	548	644
222	.301	.368	-64	-14	650	572	686
229	.283	.358	-19	-7	650	624	732
233	.274	.358	1	-6	650	645	757
239[I]	.347	.373	-161	-21	868	686	801
246	.320	.375	-109	-18	868	741	847
252	.306	.373	-75	-16	868	777	882
259	.290	.363	-36	-9	868	823	925
265	.274	.357	2	-6	868	864	957
272	.267	.352	-18	-3	877	892	980
292	.272	.353	7	-4	902	905	1009

40in

Notes: Alfalfa harvested on DOY: 169, 196, and 288.
I: Irrigations on DOY: 135, 155, 189, 215, and 235.

Decreases in soil-water content between irrigations in the 2.4- to 3.0-m zone were possibly due to drainage of water from the soil profile or to root extraction from those depths even when ample water was available above that zone. The bottoms of the access tubes were not plugged and free water did not accumulate in the bottoms of the tubes, indicating that the soil was not saturated at that depth. A simple analysis considering only the changes in soil water content at the 2.4 m depth indicated as much as 35 mm of drainage may have occurred below that depth; however, the change may have been caused by upward or lateral flow or root extraction. More definitive measurements would be required to quantify drainage.

The depletions calculated from changes in the soil-water content with time are listed in Table 1 as cumulative depletion, or net depletion, where the initial values on DOY 082 were used as the references values. The amount of water added to the profile at each irrigation was inferred from the soil-water content data. Average daily depletions, calculated from consecutive pairs of readings and corrected for any rainfall, were extrapolated for the periods before and after irrigation to the date of irrigation to obtain the irrigation amount. Calculated irrigation plus rainfall was summed from DOY 082, as listed in Table 1.

The cumulative neutron meter ET, listed in Table 1, was calculated directly as the sum of cumulative depletion for the entire 0- to 3-m profile, and cumulative irrigation plus rainfall, assuming zero drainage except for a 10-mm adjustment following the heavy irrigation on DOY 235. Space did not permit listing average daily ET corresponding to the dates of readings, but these can be calculated by dividing the increase in ET for a given period by the number of days in the period. For example, for the 7-d period from DOY 222 to DOY 229, the estimated daily N.M. ET was (624-572)/7 = 7.4 mm d^{-1}.

The last column of Table 1 lists the cumulative lysimeter ET for direct comparison with the estimated neutron meter ET. The total seasonal neutron meter ET was about 10% less than lysimeter ET when drainage was neglected. When estimated ET was adjusted for 35 mm of drainage, estimated ET was 14% less than measured. If only the upper 2 m of the profile was used in the analysis (data not shown in Table 1), estimated ET was 15% less than measured, neglecting drainage.

The underestimation with the neutron meter method possibly resulted from the upward movement of water between readings and/or to extraction of water from the lower portions of the root zone, even when soil-water contents were above 50% available soil water in the upper profile. Comparison of average rates of ET indicates that the underestimation by the neutron meter method was especially low during low ET periods. For example, between DOY 082 and DOY 131, when daily ET averaged 3.5 mm, estimated ET was 35% less than measured ET. Differences between estimated and measured ET may also have resulted from errors in estimating irrigation amounts.

Results of the sprinkler-irrigated trial are given in Fig. 2 and Table 2. The range of soil-water contents during the study was approximately between the 7/01-profile, one of the wettest, and the 9/13-profile, one of the driest. The dry sublayer was between 1.5 and 2.5 m in depth (see Fig. 2) and varied little in water content during the season. The soil profile at the time of the next to last reading, DOY 270, was drier throughout (net depletion = 44 mm) than at the beginning of the trial. Rain and irrigation at the end of the season totalling 134 mm increased soil water contents to the point that on DOY 299 they were higher in the upper 2.85 m than at the beginning of the season.

Cumulative irrigation plus rain amounts listed in Table 2 were obtained by rain gage. The capability to measure irrigation amounts with sprinkler irrigation was an advantage in estimating ET over furrow irrigation where it was necessary to infer irrigation amounts from neutron meter readings. Estimated seasonal alfalfa ET was essentially equal to applied water since irrigations were scheduled to avoid drainage and the net depletion was small. The total estimated ET on DOY 270, 859 mm, was only 9 mm less than measured ET prior to the final relatively heavy irrigation on DOY 294. The final seasonal estimated ET on DOY 299 was 3 mm greater than measured ET. In this case, the neutron meter method seemed to adequately account for the added water. However, as with the furrow irrigation trial, the neutron meter method tended to underestimate ET more during low ET periods than during high periods; i.e., 21% underestimation at DOY 140 compared with 2% underestimation for the period DOY 182 to DOY 215.

Conclusions

Results indicate that with careful field calibration and experimental technique, the neutron meter method will provide estimates of ET for deep-rooted crops, such as alfalfa, equal to lysimeter measurements of ET where irrigations are by sprinkling, a dry soil sublayer is used to define lower boundary conditions, and irrigations are scheduled to minimize drainage from the root zone. The neutron meter method tended to underestimate ET more during low ET periods than during high ET periods. With furrow irrigation and relatively wet soil in the lower root zone, the neutron meter method underestimated lysimeter ET by at least 10%, even when the effects of slow drainage were neglected. This underestimation seemed due to unaccounted for upward movement of water and possible root extraction of water from deep soil layers. This difference may partially account for the discrepancies between earlier crop water estimates obtained with the neutron meter for deep-rooted crops and the higher water-use values more recently obtained with weighing lysimeters.

Table 2. Summary data for sprinkler irrigated alfalfa, with a dry subsoil layer, where ET was estimated from soil-water contents measured throughout the growing season with a neutron moisture meter (N.M.) and alfalfa ET was measured with a weighing lysimeter (Lys.) Kimberly, ID.

	Soil profile water content			Cumulative depletion		Cumulative data		
Day of year (DOY)	0.05 m to 1.05 m	1.05 m to 2.85 m	2.85 m to 3.65 m	0.05 m to 2.85 m	2.85 m to 3.65 m	Irr. and rain	N.M. ET	Lys. ET
	$m^3\ m^{-3}$			mm				
088	.272	.124	.344	0	0	0	0	0
109	.266	.129	.340	-3	+3	24	21	43
116	.249	.125	.334	+21	+8	30	51	63
140	.221	.126	.336	+47	+6	71	118	150
154^I	.247	.117	.334	+38	+8	184	222	243
173^I	.260	.122	.335	+15	+7	274	289	333
182^I	.335	.124	.331	-64	+10	429	365	380
201^I	.280	.141	.328	-38	+13	522	484	520
215^I	.237	.138	.333	+10	+9	561	571	609
229^I	.233	.136	.330	+17	+11	613	630	665
231^I	.260	.136	.328	-10	+13	660	650	673
256^I	.229	.119	.324	+51	+16	721	822	812
270^I	.257	.117	.323	+27	+17	832	859	868
299^I	.302	.126	.328	-33	+13	966	933	930

NOTES: Alfalfa harvests on DOY: 167, 214, and 265.
I: Irrigations on DOY: 144, 152, 158, 175, 181, 189, 197, 200, 207, 223, 230, 237, 249, 252, 258, 264, and 294.

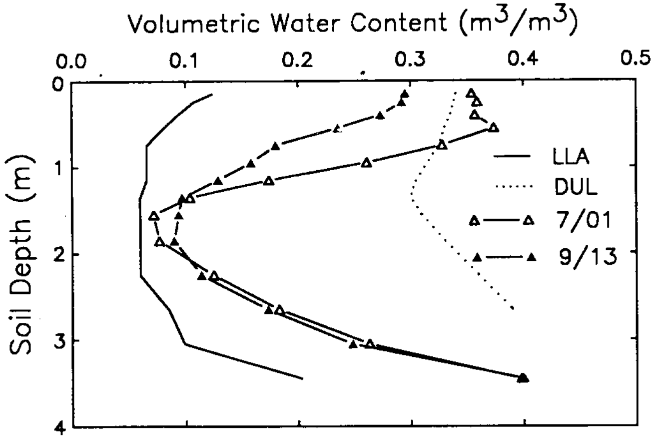

Figure 2. Soil-water content profiles for sprinkler-irrigated alfalfa.

APPENDIX I.--REFERENCES

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