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Determination of Feedyard Evaporation Using Weighing Lysimeters

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Abstract. *Six shallow, weighing lysimeters were installed near Etter, TX, to measure quasi-instantaneous evaporation rates from simulated feedyard surfaces. The data revealed a pronounced and consistent hygroscopic period during which the manure appears to have absorbed water from the atmosphere. Daily measurements during late autumn 2003 showed lysimeter evaporation to be 30% of reference evapotranspiration (ET_o) of well-watered grass. Warm-season data from an upgraded load-cell system capable of continuous monitoring showed lysimeter evaporation to be poorly correlated with ET_o, with a mean of approximately 20% and a range of 15-30%. The lower ratio in the most recent data may be attributed to (a) smaller manure particle size and greater sorptive affinity as compared to the first experiment, (b) increased evaporative demand in the warm-season experiment, which may not have been satisfied due to a flux-limiting hydraulic conductivity in the manure matrix and (c) other unknown factors that require further investigation. The hygroscopic behavior of the manure surface during the nighttime hours dramatically decreases the net daily evaporation, is loosely associated with a decrease in the vapor pressure deficit and reduces the expected water needs for feedyard dust control. Future investigations will quantify the sensitivity of the evaporation rate to surface roughness, manure particle size, target moisture content and advanced manure/soil layering procedures.*

Keywords. lysimeters, feedyard evaporation, reference evapotranspiration, North Plains Evapotranspiration Network, fugitive dust emissions.

Introduction

Evaporation from feedyard surfaces results from a complex interaction of meteorological factors and manure characteristics. The condition of feedyard manure is highly variable, and it is difficult to characterize “typical” manure. It is perhaps even more difficult to simulate a feedyard surface, particularly due to the compaction caused by feedyard animals. Sweeten and Lott (1994) state that an active feedyard surface develops a compacted manure/soil interfacial layer that acts as an effective moisture seal. On top of the interfacial layer lies the basal layer of medium-sized, compacted particles. The surface layer consists of powdery or uncompacted material and is easily disturbed by hoof action. When water is applied to the feedyard surface via precipitation, sprinkler systems or water trucks (i. e., for dust control), the basal layer may be disrupted and mixed with the surface layer by animal hoof action. If unsaturated hydraulic conductivity affects moisture flux to the feedyard surface, the depth, composition and condition of those layers will influence the evaporation rate from the feedyard surface.

The American Society of Civil Engineers defines evapotranspiration (ET) as the loss of water from a vegetated surface through the combined processes of surface evaporation and plant transpiration (ASCE, 2002). Reference evapotranspiration (ET_o), in turn, is defined as the evapotranspiration of some reference crop (e. g., grass or alfalfa) for which available soil moisture is not limiting plant growth or yield. The ratio of a crop’s actual evapotranspiration to that of the well-watered reference crop is known as the dimensionless “crop coefficient,” or K_c, which varies with season, growth stage and crop variety. We can reasonably expect the evaporation rate from an unvegetated lysimeter pan (E_p) to be less than ET_o because the manure surfaces lack the transpiration component of ET_o. But if measured daily evaporation from the feedyard surface is correlated with ET_o, which is our working hypothesis, daily feedyard evaporation can therefore be calculated from ET_o values estimated by our regional, mesoscale weather network, the North Plains Evapotranspiration (NPET) network. In turn, reliable estimates of feedyard evaporation could be used as a design basis and a management tool for water trucks or sprinkler systems (solid-set or mobile) for feedyard dust control. The management objective is to maintain optimum corral moisture conditions to reduce fugitive dust emissions and control odor potential while conserving precious ground water.

Safety Emphasis

The long-term health effects of exposure to feedyard dust have not been extensively studied for animals or humans. Acute symptoms such as watering of the eyes, sneezing, headache, temporary nausea and runny nose have been observed following short-term exposures to high concentrations of agricultural dusts. Therefore, during the grinding and preparation of manure for this experiment, all personnel were provided rubber gloves, goggles and passive, canister-type respirators to prevent any unnecessary exposure to manure-derived dust.

Lysimeter Design and Construction

System Design

We simulated the feedyard surface with an array of six identical weighing lysimeters packed with soil and feedyard manure. In 2002, the lysimeter pans were weighed manually once a day using a single, overhead load cell (model 60063-3K, Sensortronics, Inc., Covina, CA) monitored with an automatic datalogger (model CR10X, Campbell Scientific, Inc., Logan, UT). In 2003, we upgraded the system to a computer-controlled, automatic, real-time measurement system utilizing a dedicated, below grade load cell (model DSB–1K, AmCells, Inc., Carlsbad, CA) for each lysimeter and a Ethernet-based data-acquisition hardware (FieldPoint, National Instruments, Inc., Austin, TX). Data have been collected using both systems.

Lysimeter Pan Design

Six lysimeters were installed at the North Plains Research Field (NPRF) near Etter, TX. They are located on a plot of bare soil and positioned in an E-W, 1x6 array. Each pan measures 1 m x 1 m x 20.3 cm. They were constructed of 6.4 mm steel plate, and all seams were welded and water-tight. The pan bottoms were perforated with 8 mm holes for drainage. The corners of the pans were fitted with 19.1 mm eyebolts that are used to lift the pans. The pans were painted with light gray, two-part, epoxy paint. Each pan resides inside of a retaining pan which was set below the ground surface (figure 1). The retaining pans were reinforced with steel ribs to hold back the surrounding soil, to reduce sidewall deflection and to allow the pans to be weighed without obstruction or interference. A nominal, 2.5 cm gap remains between the inner surface of the retaining pan and the outer wall of the lysimeter pan. A French drain was located under each pan to prevent ponding of excess water around the electronic components.

Figure 1. View of an empty lysimeter pan mounted inside the retaining pan. Drainage holes are visible in the bottom of the pan. In the original configuration, wire slings attached to the corners of the pan were gathered to a common link and suspended from an S-type, overhead load cell on an A-frame superstructure visible in the upper left and upper right corners of the photo.

Lysimeter Pan Packing

Each pan was lined with an erosion mat to prevent soil from exiting through the drainage holes. A Sherm silty clay loam (fine, mixed, mesic Torrertic Paleustolls) was packed to maximum bulk density (ASTM D1895B) to a depth of 10.2 cm. Fresh manure was then loosely compacted to a depth of 5.1 cm, leaving 5.1 cm of freeboard in the lysimeter pan (figure 2).

Figure 2. A view of a lysimeter pan packed with a Sherm silty clay loam and topped with unprocessed feedyard manure.

Experimental Design and Results

Phase I: Single Load Cell Experiments

Initially (October 2003), the mass of each pan was measured once a day because of the limitations associated with having only one load cell. Water evaporated during the previous 24 hours was replaced each morning using a watering can. Each pan was lifted from its resting position by a manual winch and allowed to hang from the load cell for five minutes while the measurement(s) stabilized (figure 3). The results of this experimental run indicated that E_p was approximately 30% of ET_o (figure 4), with the data being adequately fit by a linear model as follows:

$$E_p = 0.3002ET_o + 0.6836 \quad (R^2 = 0.8191) \qquad [1]$$

An alternative regression forcing the linear model through the origin, which assumes that there can be no feedyard evaporation if the reference-crop evapotranspiration is zero, indicates that E_p is approximately 50% of ET_o (figure 4), but the coefficient of determination is lower. It is probable that the good fit of the general linear model (Equation 1) and the magnitude of the model's offset are attributable to leverage of the extrema on the upper end of the ET_o domain. Those phenomena are also consistent with the multi-stage drying curve posited by Lott et al. (1986), in which high evaporative demand is constrained by other flux-limiting processes (e. g., unsaturated flow to the evaporating surface), rendering a single linear model inadequate for the entire range of ET_o values. We did not collect enough data points in Phase I to evaluate the multi-stage model or to predict the transition points between flux-limiting regimes on a cattle feedyard. However, it is clear from inspection that the slope and R^2 of the regression model are artifacts of three data points lying between ETo values of 8.5 to 11 mm, each of which represented three-day weekend cycles rather than 24-hr values like the rest of the data set.

Converting those data to estimated 24-hour averages (i. e., simply by dividing all values by 3) reduces R^2 to 0.42 and increases the apparent value of K_c from 0.30 to 0.35.

Figure 3. A lysimeter being weighed using a single, S-type load cell suspended from the rolling crane. Three sides of the crane were enclosed to deflect the prevailing southwesterly winds and to minimize eddy currents.

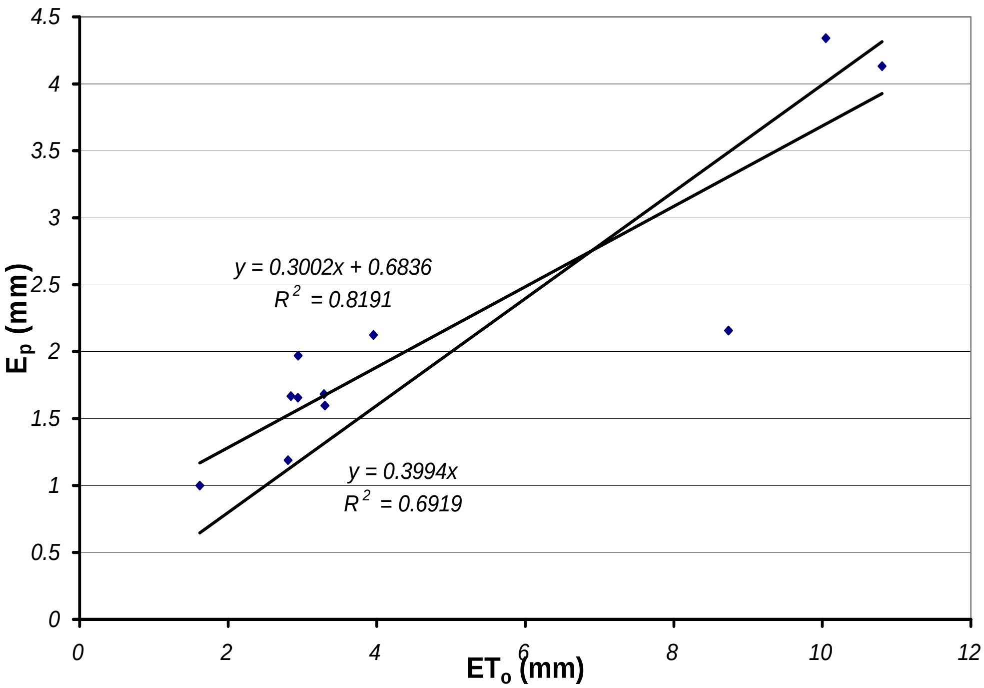

Figure 4. Cool-season evaporation data showed E_p to be approximately 30% of ET_o.

Phase II: Multiple Load Cell Experiments

In early 2004, the six lysimeters were retrofitted with individual load cells. All load cells were capable of detecting changes in lysimeter mass equivalent to 0.01 mm depth of water over the 1 m^2 surface area. As with the overhead load cell assembly, the individual load cells were calibrated using scale calibration weights. A series of weights decreasing in mass was added and removed to determine the maximum precision of mass measurement. Rain tight boxes were installed to enclose the data collection hardware. A solenoid-controlled, micro-irrigation system consisting of 24 quarter-circle micro-sprinklers (4 per lysimeter pan; model TF39 Hydro-Flo, Agrifim, Inc., Fresno, CA; 22.7 lph capacity) was installed to replace water lost to evaporation. Solenoids (model CP–100, RainBird, Inc., Glendora, CA) are manually controlled from farm headquarters via Ethernet using commercial software (Measurement and Automation Explorer, National Instruments, Inc., Austin, TX) and distributed I/O hardware. We observed sprinkler performance visually via an Ethernet-enabled video camera (model 2024, Axis, Inc., San Diego, CA) (figure 5). The pans were surfaced with high-purity manure collected from pen surfaces paved with fly ash. The manure was ground in a small hammer mill with no sieve screen. This process produced manure with varying particle sizes that appeared to represent the dry, friable manure typically found on the feedyard surface during the dry, hot summers of the southern High Plains.

Figure 5. The upgraded lysimeter project facility at the North Plains Research Field near Etter, TX.

In May 2004, we tried to reproduce the E_p/ET_o ratios measured in October 2003. The Phase II data showed that the high vapor pressure deficit (VPD) during the daylight hours evaporated water continuously from the manure pack but that the manure absorbed moisture from the atmosphere in the late evening and early morning. This “hygroscopic period” is an interesting phenomenon that was obscured by the once-daily measurements during Phase I (figure 7). Phase II data also revealed that ET_p averaged approximately 20% of ET_o (figure 6) but that there was no reliable correlation between the two quantities. We cannot yet explain that result, but probable causes include (a) the pronounced nighttime hygroscopicity during the spring and summer periods, (b) flux-limiting unsaturated hydraulic conductivities in the manure layers that limit moisture migration to the manure surface during hot, dry weather and (c) artifacts of comparing predictions of the modified Penman-Monteith evapotranspiration equation to measured evaporation from an unvegetated surface.

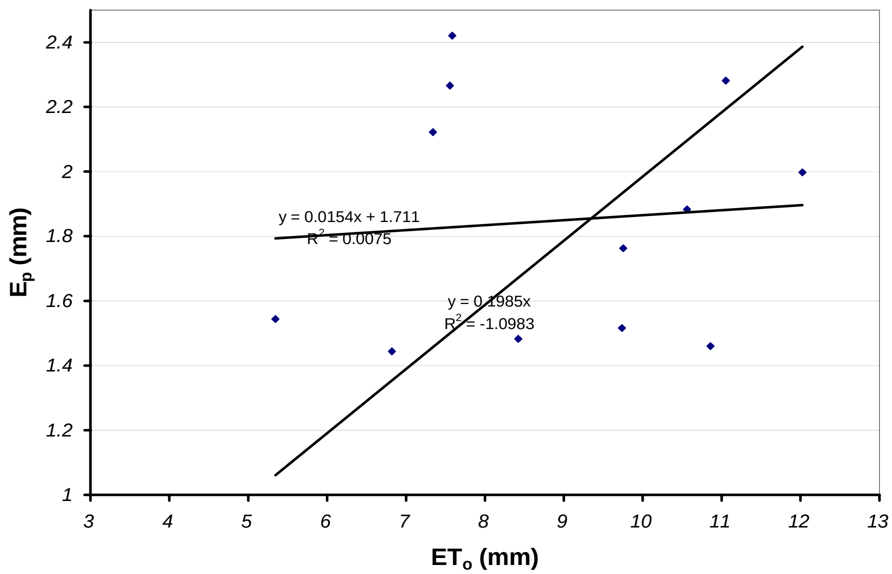

Figure 6. Data from the Phase II configuration reveals that E_p and ET_o are poorly correlated. Forcing the regression through the origin suggests that E_p is about 20% of ET_o but degrades the fit of the linear model.

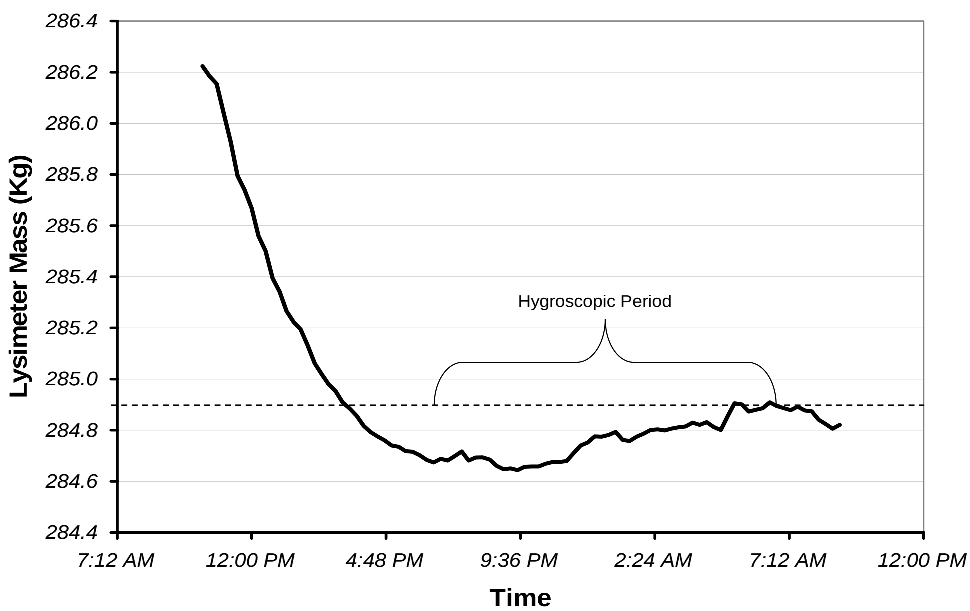

Figure 7. A typical daily plot of lysimeter mass. The hygroscopic period of the lysimeter manure is evident in the evening and early morning hours.

Conclusion

The discrepancy in the E_p/ET_o ratio between the Phase I and Phase II data needs to be resolved. The most significant experimental difference between Phases I and II was in the nature of the manure packs. The pans from Phase I were packed with manure scraped from an active feedyard. The manure was lightly packed, but it was not ground or mechanically separated. The pans from Phase II were lightly packed with ground manure. The ground manure was well graded but had a smaller median particle size. The smaller particles comprising the Phase II manure pack may have a stronger affinity for water than the larger, conglomerated particles from Phase I. The smaller particle size also allows for the manure to be compacted to a higher bulk density, perhaps reducing permeability to liquid water or water vapor. Crusting of the ground manure surface has also been observed, which may be limiting moisture flux via lower hydraulic conductivity. Finally, the hygroscopicity of the manure reduced the net daily evaporation dramatically during warm weather.

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