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Modeling The Timing And Amount Of Drainage Water Under Turf Grass Water Use Atfour Golf Courses In Logan, Utah (Usa) Under Non-Weighing Lysimeters.

*Dlamini[1],M. V.
[1]*Department of Agricultural and Biosystems Engineering, Faculty of Agriculture, University of Eswatini, Private Bag, Luyengo, Luyengo, M205. Swaziland.*

ABSTRACT: *A mathematical soil water balance model for non-weighing drainage lysimetersthat simulates the occurrence (timing and amount) of drainage water was developed for turfgrass water use conditions. A pair of non-weighing drainage lysimeters were used, located in four locations in the State of Utah (USA): Logan Golf and Country Club, Murray Golf Course, Brigham Young University (Spanish Fork) Experiment Farm, and Sunbrook Golf Course (St. George). The amount of drainage water collected after irrigation and rainfall was measured with a bucket located underground adjacent to the lysimeters. The timing was determined using CR10X and CSI 21X dataloggers (Cambell Scientific Inc.) connected to a TE525 (6.06 inch) rain gauge (Texas Instruments Inc.). The duration of the drainage time ranged between 21 to 37 hours and the drainage rate from 1.3 l/hr to 9.7 l/hr. The drainage hydrograph from each lysimeterwas better approximated using a power curve function. The packing of soil in each pair of lysimeters was observed to be heterogeneous.*

KEY WORDS: *Lysimeter, drainage, non-weighinglysimeter, golf course, modelling.*

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I. INTRODUCTION

A lysimeter is a tank placed in the ground that isolates the soil mass and vegetation ensuring that all water enters or leaves at controlled points. Lysimeters make it possible to accurately monitor the amount of water required to sustain plant growth inorder to determine evapotranspiration (ET) by plants growing in the lysimeters. They are generally used to measure the effects of soil, vegetation, and climate on the water balance of crops (Pereira et al., 1995; Allen et al., 1991; Klocke et al., 1991; Hill and Allen 1991; Hill et al, 1989) by attempting to represent as close as possible actual field conditions (Vilim, at al., 2013).

The movement of water in the soil profile is characterized by the suction head gradient (matric potential) and the difference in soil moisture content, mostly represented by the soil characteristics curve. The soil moisture characteristics curve is strongly affected by the soil texture (the particle size distribution) and the soil structure (the arrangements of soil forming particles) (Hillel, 1971). The relationship between the metric potential and soil moisture is not generally unique and single valued (Kirkland et al., 1992; Celia et al., 1990; Feddes et al., 1988). The design of a particular lysimeterdepends on the data to be obtained (van Unold and Fank, 2007) and the resources available to build the equipment (Robbins and Willardson, 1980). Weighing lysimeters determine ET directly by the mass balance of the water (Wright, 1996; Phene et al., 1991) as contrasted to non-weighing which indirectly determine ET by the volume balance method.

Lysimeters are important because they measure the effect of soil, vegetation, and climate on the total volume balance by isolating the soil mass and vegetation from the impact of surrounding groundwater movement (Riley et al., 2009). Water can drain from the lysimeter only when the bottom layer is saturated, under zero pressure head or greater. The placement of lysimeters is destructive to the natural conditions of the field soil, including the soil structure, texture, and compaction with consequences to the soil aeration, circulation of water, penetration of roots, and on heat movement. Common environmental problems that may affect the use of lysimeters may include: 1) the two-dimensionality of lysimeter boundaries; 2) vegetation density differences compared to the surrounding area; 3) bulk density and lysimemeter depth effects on root development; and 4) the effect of soil moisture profile distribution within the lysimeter on evaporation and soil moisture movement and extraction.

Many lysimeters are constructed of steel which may result in wall heating and likelycause a lag between the lysimeter ET and the amount of drainage water observed within a given time, particularly during the morning and the opposite effect during the afternoon. Dugas and Bland (1991) found much greater diurnal damping depths for soil temperature in small and medium lysimeters compared to larger weighing lysimeters and the field soil for bare soil conditions and steel walled lysimeters. Concrete has sometimes been used for lysimeters, but concrete walls have to be thicker than steel to have a similar effect.

The objective of this research was to model the occurrence (timing and amount) of drainage water under turf grass water use conditions in four golf courses in Logan, Utah (USA) under non-weighing lysimeters.

II. MATERIALS AND METHODS

Experimental area

The research was carried out at four Golf Course sites in the State of Utah (USA): Logan Golf and Country Club, Murray Golf Course, Brigham Young University (Spanish Fork) Experiment Farm, and Sunbrook Golf Course (St. George) (Dlamini, 2003). The Logan Golf Course is situated on the east side of Cache Valley in Northern Utah (Logan, UT: latitude 41^{o}46′ N, Longitude 111^{o}48′ W, and elevation 1460 m). The Murray Golf Course is located at latitude 40^{o}47′ N and longitude 111^{o}58′ W at an elevation of about 1288 m. The Spanish Fork Golf Course is located at 40^{o}5′ N and longitude 111^{o}36′ W at an elevation of 1439 m. The Sunbrook golf course is located at latitude 37^{o}6′ N and longitude 113^{o}34′ W at an elevation of about 845 m. All the golf courses are irrigated by sprinkler systems.

At the Logan golf course, the turf is a Marion Kentucky Blue Grass (Poapratensis L. var. 'Merion'), cut at 3.81 cm in the rough, where the lysimeters are located, and at 1.91 cm in the fairways. In summer, irrigation is about every other day, three times a day, each irrigation lasts about 13 minutes. At Murray and Spanish Fork golf courses the arrangement is the same as in Logan, except that the frequency and amount of irrigation depends on weather data. Normal mid-summer irrigation target is about 1.27 cm, applied three times per week. At the Sunbrook golf course, the turf is a mixture of Perennial Rye grass (Loliumperenne L.) (Palmer / Prelude) mixed with some common Bermuda grass (Cynodondactylon, L.). The grass is cut about once a week to maintain a height of 2.86 cm. The frequency of irrigation is daily, with a gross application of about 0.46 to 0.61 cm.

The management of the grass in the lysimeters (irrigation, fertilization and cutting) at all the sites was done by the Golf course personnel in a similar manner to the surrounding areas.

Soil description

The Logan Golf Course site is situated on rather narrow lake terrances and broad deltas along the east side of Cache Valley. The soils are Ricks gravelly loam, 0 to 3 percent slopes (USDA-Soil Survey, 1974). They are fairly easy to till, but very gravelly from a depth of 38 to 76 cm. Permeability is moderately rapid; 5 to 16 cm/hr. Runoff is slow with a slight hazard of erosion. The water holding capacity ranged from 8 to 10 cm to a depth of 1.5 m.

At Murray golf course, the soils are mixed alluvial, a miscellaneous type that consists of somewhat poorly drained, highly stratified alluvium. It is undulating on recently deposited flood plains and stream meander belts adjacent to the Jordan River. Texture ranges from clay to sand, and commonly there may be gravelly strata. During the construction of the golf course, top soil had to be brought from outside with a different description from the surrounding soils.

At Spanish Fork golf course, the soils are mainly clay loam of the Timpanogos series (USDA-Soil Survey, 1974). They consist of deep, well drained, and moderately well drained soils on slopes of 0 to 3 percent. The top layer ranges from 18 cm to 25 cm in thickness. Some fine gravel can be found on the surface in some places, with gravel and sand common below a depth of 114 cm.

The soils at the Sunbrook golf course are Junction fine sandy loam, 1 to 2 percent slopes (USDA-Soil Survey, 1977). The Junction series consists of well-drained soils on alluvium washed from sandstone and shale. The soils are red fine sandy loams to a depth of more than 1.5 m. Runoff is slow and the hazard of erosion is moderate, with moderately rapid permeability. They have an available water capacity range of 15 to 20 cm to a depth of 1.5 m.

Experimental procedure

Two non-weighing (drainage) lysimeters were installed at each of the four sites. The lysimeters at the Logan golf course were installed in the fall of 1990 and the first season of data collection began in spring of 1991 until 2002 (Dlamini, 2003). The lysimeters at Murray and Sunbrook were installed in November 2001 and data collection began early in 2002. At Spanish fork they were installed in April 2002 and the second one in May 2002.

The lysimeterswere steel tanks 1 m^2 by 0.46 m deep at Logan golf course and 1 m^2 by 0.76 m deep at Murray, Spanish Fork and Sunbrook with a perforated 76 mm diameter pvc pipe placed diagonally across the bottom, covered with a sand envelop and an outlet in the corner. The lysimeters were placed at a depth greater than the rooting depth of turfgrass (30.5 to 38.1 cm as reported in Hill et al., 1996) and therefore considered not limiting to the growth of the turf. The outlet pipes were 32 mm in diameter atSunbrook, Murray and Spanish Fork, and 25 mm at the Logan golf course. They were fabricated from 2.4 mm thick steel. Once installed, they are refilled with soil to simulate the natural surrounding condition and a sod of turf placed on top. Irrigation and rainfall was measured with 102 mm diameter rain gauges placed in 153 mm diameter pipes sunk into the ground outside of the lysimeters at opposite corners.

Drainage water was collected in a 25 liter bucket located in a manhole adjacent to each lysimeter. The top of the manhole (a 380 mm class 9 pvc pipe) was above ground level and covered (with a 394 mm steel lid) to ensure that runoff, irrigation and rainfall water doesnot enter the collection bucket.

Data Collection

Data collection was initiated in the spring after snow melt and continued on into fall or early winter, until significant snow cover on the ground was observed. Weekly visits were made to the lysimeter sites and depending on the amount of drainage, these became twice weekly in late May to August. At each visit, water collected in the two rain gauges and the bucket was recorded.

Drainage Timing

The lysimeters were wetted with a known volume of water (25 L) and the drainage timing and amount observed. First, they were primed to remove any trapped air that might obstruct the flow of water during infiltration. Drainage timing was measured using automatic tipping bucket rain gauges connected to a datalogger with tip setting recorded every ten seconds and readings totaled after every ten minutes. A standard 152.4 mm diameter tipping rain gauge (TE 525, Texas Instruments Inc.; Texas) connected to a CSI 21X data logger were placed in each drainage manhole per lysimeter to record the change in drainage discharge with time.

III. RESULTS AND DISCUSSION

Drainage hydrograph model

In the hydrograph model the amount of water lost from the lysimeter profile as deep drainage was taken as the difference between the total water infiltrating and the cumulative crop water use over a specified time period. The cumulative crop water use was calculated following the methods described by Hill (1991, 1994, and 1997); Hill and Allen (1991) and Hill et al., (1996).

The drainage hydrograph model calculates the time from the beginning of irrigation and or rainfall to the start of drainage. It is assumed that the rate of water movement in the soil is dependent on the initial water content at the time of wetting. The water content was related to the time of drainage by a simplification of the Green and Ampt expression for the drainage of a uniform column of soil as shown in Eq (1);

$$t = \frac{\Delta\theta}{K}\left[(L-z) + h_f \ln\frac{z+h_f}{L+h_f}\right] \qquad (1)$$

where, t is the time to the beginning of drainage after wetting, minutes; Δθ is the water content difference; h_f is the soil water pressure head between the saturated material yet to drain and the fully drained material above it separated by a sharp front (the air entry pressure value); L is the depth of the lysimeter, cm; z is the vertical ordinate measured positively upwards; and K is the saturated hydraulic conductivity. The saturated hydraulic conductivity and the air entry pressure value can be obtained from published tables in the literature for the soils considered. Equation (1) is normally solved to obtain the time when the drainage front reaches any prescribed value of z. At the bottom of the lysimeter where drainage occurs, the value of z is zero. The air entry pressure value is considered positive throughout the profile. At the Logan Golf course, the west lysimeter drained quicker than the east lysimeterindicating the the two lysimeters had different hydraulic conductivity values.

The physical properties of the soil that contribute to the flow and transport are extremely heterogeneous and complex, particularly the expected drainage as macro- and mesopore processes substantially control the subsurface flow. The water flux or Darcy velocity (Ross, 1990; Lafolie, 1991; Smith et al., 1995; Kalbus et al., 2006) was given by Eq (2) and the mean apparent / pore velocity by Eq (3);

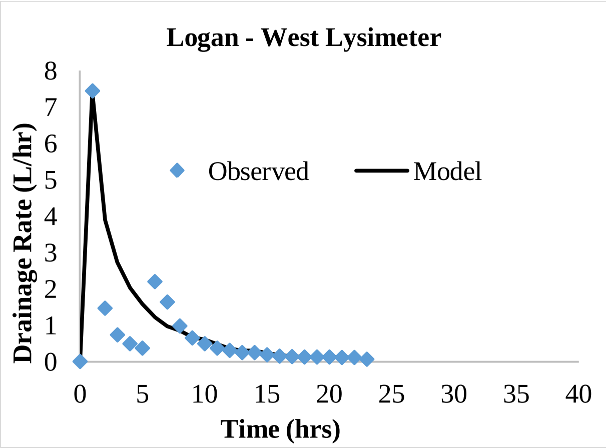
$$q = \frac{Volume\ Added}{A*t} \qquad (2)$$

$$v = \frac{q}{\Delta\theta} \quad (3)$$

where q is the water flux velocity (m/min); A is the area of the lysimeter (m^2); t is the time taken for water to emerge at the bottom of the lysimeter as drainage; v is the mean apparent / pre velocity (m/min) and Δθ is the water content at time of watering. The mean apparent velocity indicates the characteristics of the soil profile at a particular water content.

The hydrograph model

To be able to successfully model the drainage from the lysimeters, the time to peak flow was required. The observed and modeled drainage hydrographs are shown in figures 1 – 4.



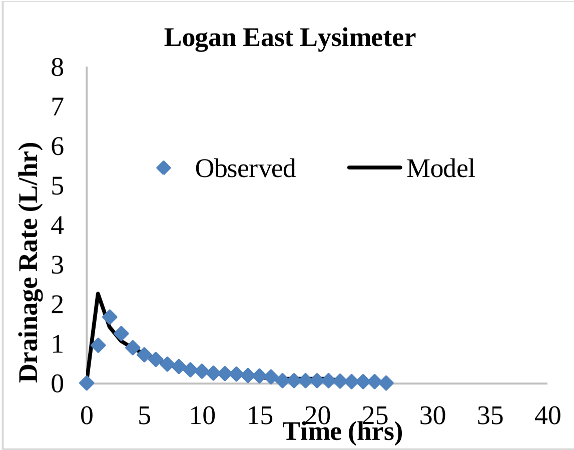
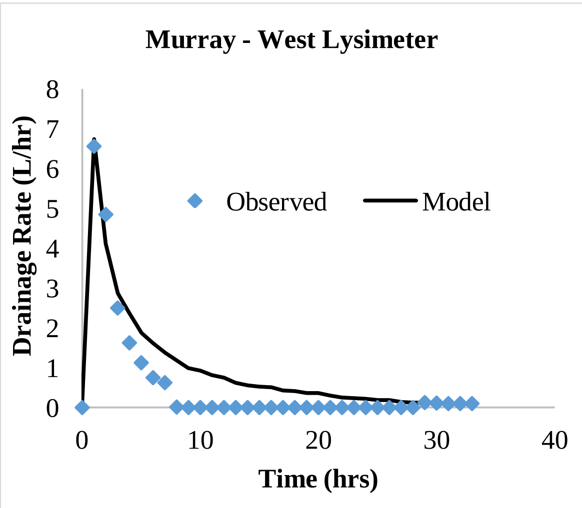


Fig. 1. Observed and modeled hydrographs for the West and East lysimeters at Logan Golf Course, 2002.



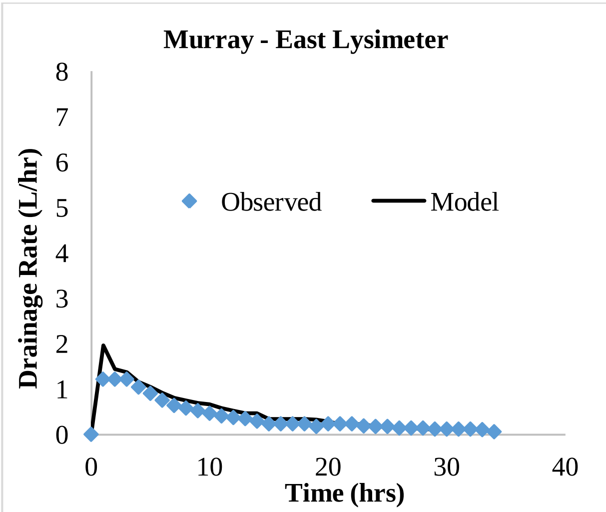


Fig. 2. Observed and modeled hydrographs for the West and East lysimeters at Murray Golf Course, 2002.

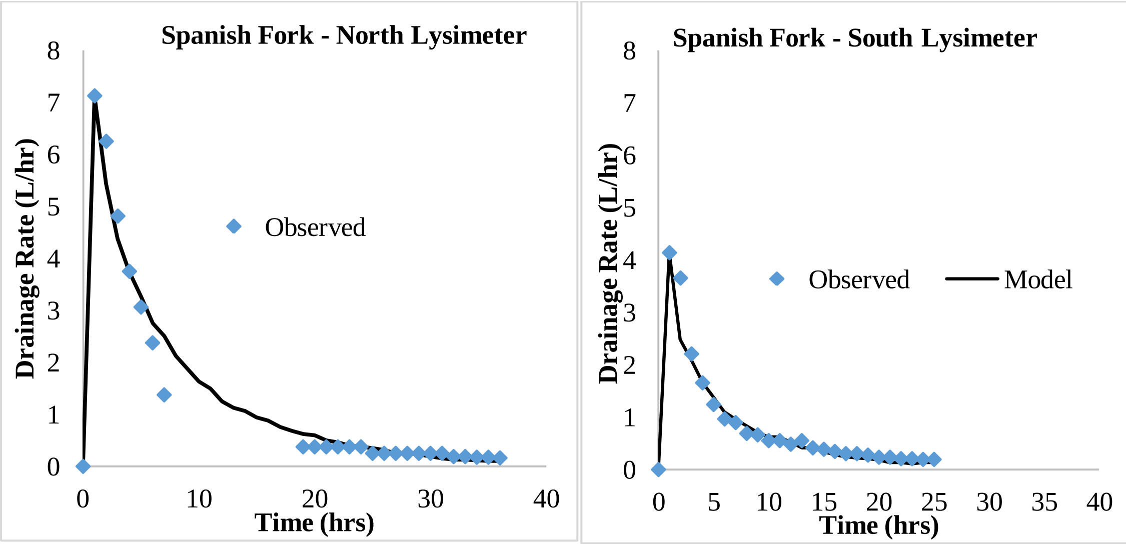


Fig. 3. Observed and modeled hydrographs for the north and south lysimeters at Spanish Fork Golf Course, 2002.

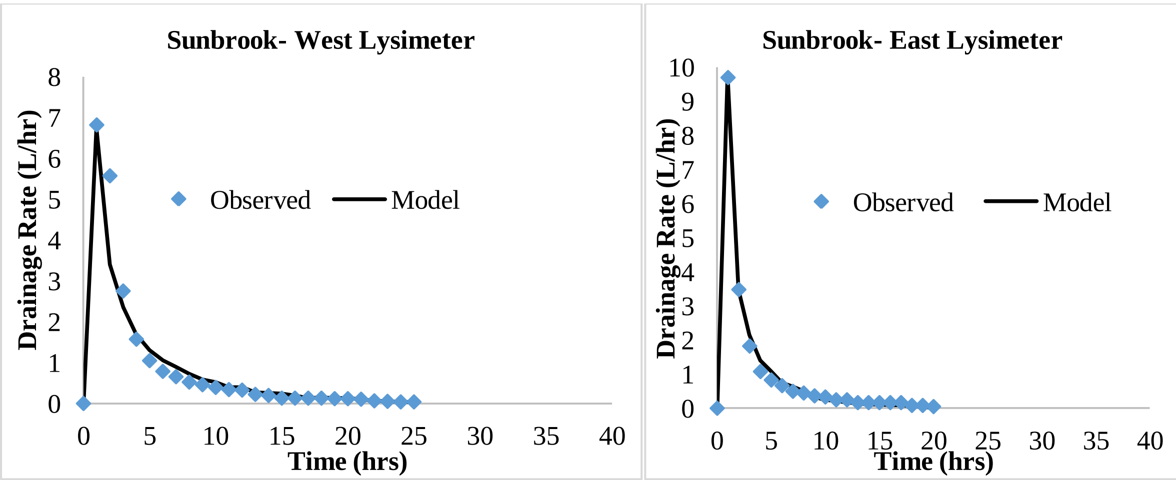


Fig. 4. Observed and modeled hydrographs for the north and south lysimeters at Spanish Fork Golf Course, 2002.

The model correctly fitted the peak of all the lysimeter sites. For most of the sites drainage occurred for a period of within 25 hours or less except for the Murray sites where it took more than 30 hours to drain. For the Spanish Fork north lysimeter, the model could not fit properly the falling limb of the hydrograph. For Logan, Murray and Spanish Fork there were differences in the peak drainage rate of the hydrographs between the two lysimeters, with one having a smaller peak than the other. This could be caused by differences in the soil packing of the two lysimeters, which tended to influence the water flow. Vilim et al. (2013) observed that free drainage lysimeters are more reliable for heterogeneous soils but their efficiency depended on the texture of the soil and also on the soil anisotropy. For all sites except at Murray Golf course, the peak drainage flow occurred about 30 minutes, from the beginning of drainage. At Murray Golf course this was observed to be about 40 minutes.

Each hydrograph was characterized by a peak, which could be related to the total volume of drainage by a linear function of the form (Eq. 4):

$$V_{max} = 0.1178\, D_p + 0.0834 \qquad (4)$$

where V_{max} is the maximum volume of drainage (L) per unit time during the drainage period, and D_p is the total drainage expected. The function fitted with an R^2 value of 0.98. The hydrograph consisted of two phases, an advance (rising) and a recession (falling) phase. The two hydrograph phases have different characteristics. The advance phase generally takes a shorter time, while the recession phase generally takes longer. The two phases were modelled using equation (5):

$$DFR = k_1 t^{k_2} e^{k_3 t} \tag{5}$$

where DFR is the drainage flow rate in units of volume per unit time (liters/hr); t is the time (hours), k_1, k_2, k_3 are empirical parameters. The time (t) varies from zero to the time where DFR is maximum to when it is zero. The parameter k_1 is related to the total peak drainage (D_p), and hence, to the total drainage by equation (6);

$$k_1 = 1.095\, V_{max} = 1.095(0.1178\, D_p + 0.0834) \qquad (6$$

which simplified to

$$k_1 = 0.129 D_p + 0.0913 \tag{5}$$

which relates to the peak of the hydrograph. The parameter k_1 is generally positive, with the parameter k_2 and k_3 negative. Parameter k_2 determines how quick the drainage flow rate decreases with time (the curvature), and k_3 determines how it approaches zero.

IV. CONCLUSION

A mathematical soil water balance (drainage) model for non-weighing drainage lysimeters, which simulates the occurrence (timing and amount) of drainage water for turf grass water management was developed for four golf course sites in the State of Utah. There were differences in the peak drainage amounts for lysimeters at Logan, Murray and Spanish Fork. For all the sites, the peak drainage rate occurred one hour after wetting. The duration of the drainage time ranged between 21 to 37 hours and the drainage rate from 1.3 l/hr to 9.7 l/hr. For most of the lysimeter sites, drainage stopped after less than 30 hours from the time of wetting except from the Spanish Fork north lysimeter and both lysimeters at Murray Golf Course.

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