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A LYSIMETER FOR THE PAWNEE SITE

Joe D. Armijo, J. R. Nunn, George Twitchell,
and R. D. Burman
Agricultural Engineering Division
University of Wyoming
Laramie, Wyoming

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ABSTRACT

"Undisturbed" is the unique word which describes the weighing lysimeter, installed for studies on prairie grassland at the Pawnee Site. Previously constructed lysimeters, designed for irrigated row crops, have used installation techniques which were highly disturbing to the soil and perimeter surface conditions. Such disturbance and resulting necessary cover regeneration were not considered applicable to delicate prairie grassland. The sparse nature of the grassland surface dictated a need for a large surface area to adequately obtain a representative sample, and for access to the lysimeter to be sufficiently removed from the soil container to minimize effects of unnatural area.

The lysimeter description is followed with a discussion of the continuous and integrated data recording device and overall performance of the system.

DESCRIPTION AND INSTALLATION

The lysimeter system is shown schematically in Fig. 1. A cylindrical tub, containing the undisturbed soil core, fits concentrically and freely within an outer retaining silo. The tub rests on a mechanical balance connected to an electronic strain gauge load cell. The mechanical scale counterbalances most of the soil weight, while the load cell detects, through proportional output voltage, the weight changes of the soil caused by water losses or gains. A tunnel houses the load cell assembly and scale counterbalance mechanisms and provides service access via a manhole entry.

Soil Container

The container is a steel cylinder[1] with a basic inner diameter of 10 ft (3.05 m) and a depth of 4 ft (1.22 m). The top 8 inches (20.32 cm) is modified to an inner diameter of 10.42 ft (3.18 m) to minimize the unnatural surface area to 1.9%. The container is made of 1-inch (2.45 cm) thick steel, a factor which necessitated recessing the cylinder below the ground surface to avoid heat-sink phenomena. The top 8 inches referred to above was constructed of 1/8-inch (3.18 mm) thick steel by welding horizontal and vertical elements onto transitional fabrication with the container in final position. The bottom of the container consists of a 1/2-inch (1.27 cm) steel plate welded to the cylinder.

Isolation of the undisturbed soil core was accomplished by the following method. An open-ended cylinder 5 ft (1.52 m) in depth was notched on one end to facilitate a special, heavy steel cross yoke. The center of the cross yoke accepted the drive shaft of a large caisson drilling rig[2], which rotated and screwed the cylinder into the ground. This operation was aided

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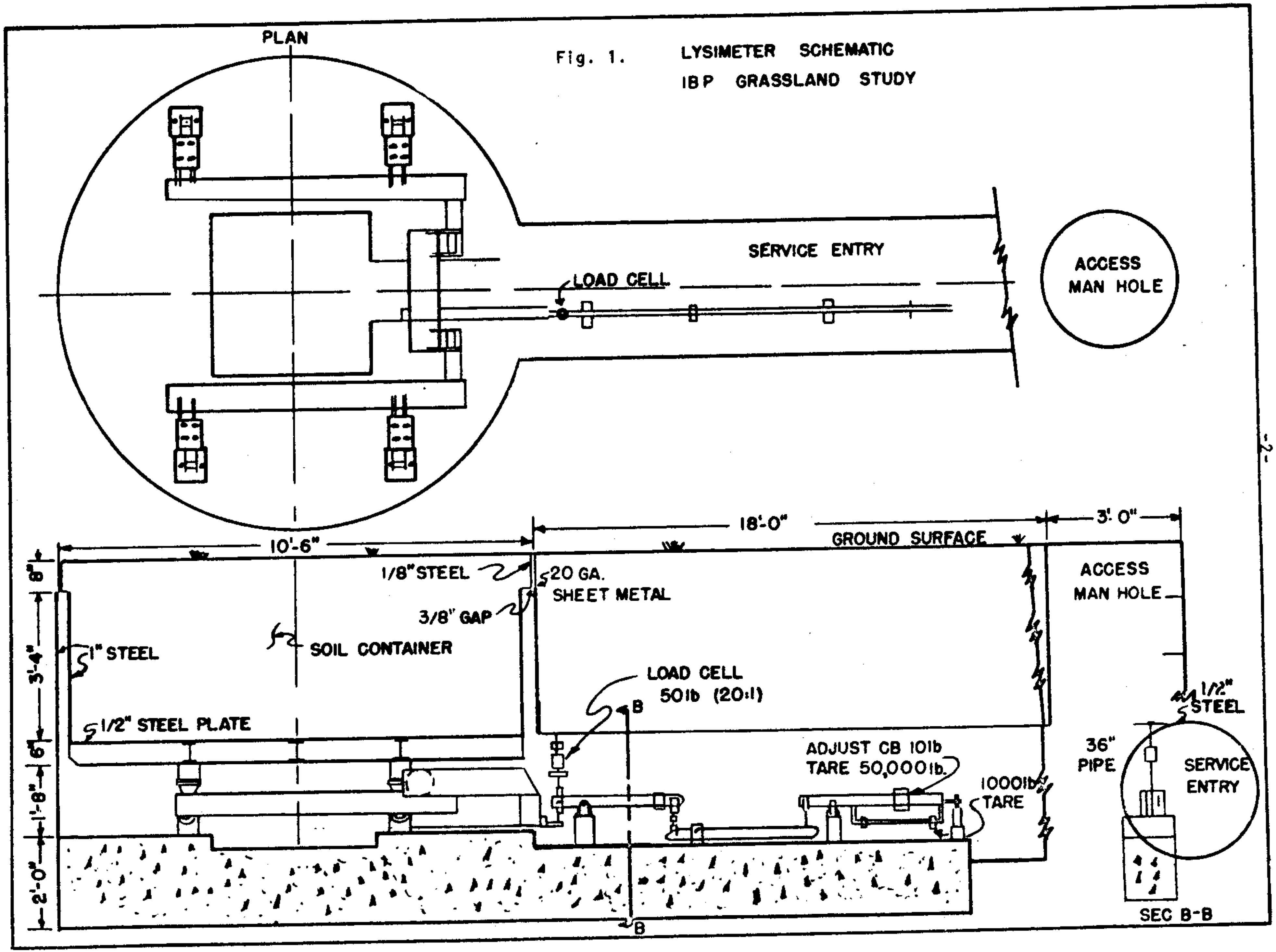
[1] Thompson Pipe and Steel Co., Denver, Colorado.

[2] Meredith Drilling Co., Inc., Denver, Colorado.

Fig. 1. LYSIMETER SCHEMATIC
IBP GRASSLAND STUDY



by two levels of removable bracing to avoid distortion, a beveled screwing edge, and minor water lubrication. The soil is a tight uniform silt, essentially non-plastic, but with sufficient cohesion to facilitate the operation. Minor plowing effects occurred adjacent to the cylinder walls, but otherwise the enclosed soil core appeared undisturbed.

Following the caisson operation (a period of 2 hr), the enclosed core was allowed to fallow, except for occasional watering to deter burning, through the hot summer. During this time the retainer site (a few hundred feet distant) was prepared. During the fall the core area was excavated, isolating the cylinder, and the bottom was attached. This was done by hand-augering horizontal bores beneath the cylinder, anchoring steel guide beams, placing the steel plate onto the extended beams, and pushing the plate under the cylinder. A 100-ton hydraulic hand jack coupled with a large concrete footing provided the thrust. The bottom plate was then temporarily welded, with angle iron struts, to the cylinder.

To install the drainage assembly (described later) on the bottom plate, a crane was used to tip the cylinder onto its side, using precautionary measures against sluffing and distortion. The bottom of the cylinder was released, drainage plates were attached, the bottom was rewelded, and the cylinder was set back into an upright position and permanently welded.

Cutting of the top 20 inches (50.8-cm) of the steel cylinder was done to remove the notched portion and to facilitate the special rim which extends to the surface. A carbon-arc blow process was used which necessitated application of copious amounts of water to avoid burning. Steel-belt transitional fabrication atop the resulting ragged edge followed, and the soil core was ready for insertion into the retainer. Final positioning of the core within the retainer was done by tediously raising and lowering the core using three hydraulic jacks from beneath. The 8-inch (depth) surface rim was then assembled and painted. It was necessary to place a strip of sod 2½-inches wide (6.35 cm) around the perimeter to fill in the void created by the surface rims.

Retaining Silo

The retainer is a cylinder of 1-inch thick steel with a depth of 7½ ft (2.29 m) and an inner diameter of 10½ ft (3.20 m). This diameter allows an air gap of 2 inches (5.08 cm) between the walls of the concentric cylinders. The cylinder, recessed into the ground 8 inches, is topped with a 20-gauge (.0375 inch, 0.95 mm) sheet metal rim. The bottom 2 ft (0.61 m) of the retainer contains a reinforced concrete footing, anchor bolts, and pads to support the scale mechanism.

Installation of the retainer was accomplished utilizing silted work platforms, conveyor systems, dump truck, canvas covers, and rudimentary hand tools. The cylindrical excavation was dug with pick and shovel, using the conveyor system to remove the excavated material. Preservation of perimeter surface conditions was achieved by removing and rotating, daily, the platforms, etc., and allowing the grass to recover.

Placement of the concrete was done quickly using 1-inch plywood sheets to spread the wheel loads of the ready-mix truck. Accuracy of placement of anchor bolts and pads was assured with the use of a precise plywood template.

Tunnel

The tunnel, 18 ft (5.49 m) in length and 3 ft (0.91 m) inner diameter, is lined with ½-inch (1.27 cm) thick steel. The manhole is similar and has a depth of 7 ft (2.13 m). A concrete footing protrudes through the tunnel floor and supports the counterbalance mechanisms. Conventional lighting was installed throughout.

Construction of the tunnel began prior to concrete operations by cutting a 3-ft diameter hole in the wall of the retainer. Excavation of the tunnel followed, using a pick, spade, and bucket routine. The manhole was set, utilizing a mechanical auger. To line the tunnel, a steel-beam track was fixed to the tunnel floor and extended into the retainer area. Using a tripod, hoist, and elevated steel beam railway at ground level, 5-ft sections of the pipe were rolled to the retainer rim and lowered onto the beam track. A successive jacking and welding method was used to pull the pipe lining into the tunnel.

Placement of the tunnel footing required cutting discontinuous portions of steel out of the floor and excavating. Reinforced ready-mix concrete was placed and anchor bolts and pads set.

Weighing Mechanism

The soil container rests on a commercially available[3/] 50,000-lb. (22,727-kg) capacity floor stand tank scale (Fig. 1). The soil container sets on a steel beam weighbridge which is bolted to four girder chairs (Fig. 2). The chairs transfer the dead load to fulcrum pivot assemblies which are supported by fulcrum stands positioned on the concrete footing. The four fulcrum pivots, in turn, transfer the load to two main pipe levers (Fig. 2). Two splice arms, connected to the main pipe levers, transfer the load to a transverse pipe lever through two fulcrum pivots (Fig. 3). Connected to the transverse pipe is a longitudinal beam which begins the counterbalance mechanisms (Fig. 4). Through a series of shaft-like arms, supported by three fulcrum pivots, the load is counterbalanced at the end of the system by a 10-lb. (4.54-kg) weight and a ½-lb. (227-g) weight (Fig. 5). Counterbalance capacity of the large weight is the full range of 0 to 50,000 lb., while the small weight allows fine adjustment with a range of 1,000 lb. (454.55 kg).

[3/] Cardinal Scale Manufacturing Co., Webb City, Missouri.

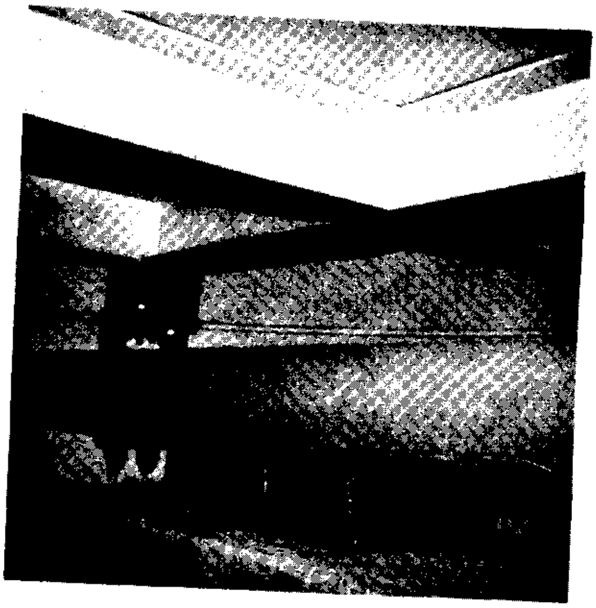


Fig. 2. Beam weighbridge, girder chair, fulcrum pivot assembly, and main pipe lever.

Fig. 3. Transverse pipe lever accepts load transfer from splice arms (center right) through fulcrums, and transfers load to longitudinal beam; drainage tank (center).

Fig. 4. Counterbalance arms and load cell beginning at end of longitudinal beam.

Fig. 5. Counterbalance mechanisms and output voltage amplifier, in tunnel with manhole entry ladder.

Nearly all of the soil container weight is counterbalanced with the scale system, leaving a maximum of 500 lb. (227.27 kg) as a weight range in which the electronic load cell functions. As the soil container gains or loses weight, the counterbalance weights are manually adjusted to maintain the load cell in its functional range.

The scale system has a mechanical advantage of 20.1. All pivots are matched ground knife-edges to increase precision. Operational movement, non-discernible to the eye, is essentially nil, a condition which enhances the life and effectiveness of the edges. Placement of the counterbalance mechanisms within the tunnel resulted in a dead air space beneath the lysimeter equal to less than 50% of the soil container volume.

Load Cell

A precision strain gauge load cell[4/] (Fig. 4) is used to translate weight changes in the lysimeter to voltage changes. The load cell is a tension type with a capacity of 50 lb. (22.73 kg) and a manufacturer's overload rating of 250%. The output is 3 mv per volt input to the strain gauge bridge. Constant voltage input is supplied by a commercial, high stability precision DC power supply[5/]. Load cell output is amplified by a factor of 250 (to 0 to 5), utilizing a chopper stabilized operational amplifier[6/] in a recording system designed at the University of Wyoming (Davies, 1967).

Recorder

The load cell output and soil temperatures are recorded on the existing Pawnee Site data acquisition system (Nunn, 1971). This system, utilized for

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[4/] Baldwin-Lima-Hamilton, Waltham, Massachusetts (Model T3P1 50-lb. capacity).

[5/] Raytheon Co., Sorensen Operation, Manchester, New Hampshire (Model QHS40-.5).

[6/] Burr-Brown Research Corp., Tucson, Arizona (Model 3355/25 Power Supply Model 527).

meteorological data acquisition, continuously integrates and records 1-min values on 110-inch magnetic tape for 36 parameters simultaneously. The system records and counts (0 to 1,000), with one count equal to .5-lb. (.227-kg) weight changes at the lysimeter.

Drainage System

To create and maintain moisture conditions within the soil container similar to conditions in the natural soils surrounding the lysimeter, a drainage system was installed. The primary components of the system are 16 sintered stainless steel suction plates[7/] (15-cm^2), utilized in a design of Ritchie and Burnett (1968). The porous plates, used in a sandwich with plexiglass and spacer, form a collecting basin from which a stainless steel tube is connected to drain water. The tubes drain to a common manifold which is connected to one tube which extends through the wall of the soil container.

The one tube drains, by gravity, into a 20-gal (75.7-liter) plexiglass drainage tank (Fig. 3), which hangs from the steel-beam weighbridge. Within the drainage tank is a pump which, upon submersion, automatically ejects the water through an outlet tube fixed to the tunnel roof.

Following installation of the plates (described under soil container), a porthole was cut topside while the soil cylinder rested on its side. Through this porthole, washed sand was poured and vibrated, resulting in a depth of 4 inches (10.2 cm) covering the suction plates. The sand prevents dogging of the plate pores and enhances drainage from the entire bottom of the soil core.

Moisture and Temperature Monitoring Devices

To compare moisture and temperature gradients within the soil core to corresponding gradients in the surrounding natural soils, monitoring devices were installed. Electrical diodes, inside and outside the soil core,

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[7/] Grade H 1/8-inch thickness, Pall Trinity Micro Corp., Cortland, N.Y.

continuously relate the two soil temperature profiles, while four access tubes allow periodic moisture determinations by nuclear methods.

PERFORMANCE

In general, performance of the lysimeter has exceeded expectations. A sensitivity equivalent to 0.001 inches (0.025 mm) of evapotranspiration is attainable. In actual weight change, this amounts to 0.443 lb. (0.20 kg), which represents approximately 1/100,000 of the total soil container weight. Repeatability, nonlinearity, hysteresis, and drift with time have not, to date, caused any problems. Effects of wind on output voltage are averaged by the continuous integration process of the recorder. Temperature changes within the tunnel are not great, occur gradually in time, and do not appear to affect the electronic apparatus.

Operation

The recorder limitation of 0 to 1,000 counts and the desired sensitivity dictate operation of the system. The present proportion of 0.5 lb. (0.227 kg) to one count and the corresponding 500-lb. (227.27 kg) load cell range results in infrequent (twice weekly during spring) adjustments of the tare mechanisms. The 500-lb. range is equivalent to a thunderstorm of 1.13 inches, not uncommon in the prairie country. Should a storm amount exceed the capacity of the recorder, determination of the total precipitation is obtainable by observing the tare increase on the graduated tare bar. A linear graduation of the bar was done during calibration, which makes possible a manual adjustment within 2 lb. (0.91 kg), or 0.0045 inches of precipitation should evapotranspiration during an unattended weekend result in bottoming out of the recorder, known weights can be placed on the soil core until the recorder is, again, in range. Obviously, minor amounts of precipitation during brief showers could be missed.

The maximum range of the load cell of 1,000 lb. (454.54 kg) can be realized by adjusting the count-weight proportion of the system.

Calibration

Calibration was accomplished by covering the soil container surface with a polyethylene film to prevent moisture loss and utilizing a steel snap ring to hold it in place. A stock tank was inverted over the lysimeter to create calm conditions for easier calibration. Through a hole in the tank bottom, standardized weights were added and corresponding output voltages were observed utilizing a potentiometric bridge. Nonlinearity (including hysteresis) of the relationship between load cell voltage output and weight changes varied from essentially nothing during still dawn hours to 0.3% during windy calibration conditions. Despite the stock tank cover, wind affected the calibration. Fig. 6 illustrates a typical calibration plot. Calibrations were also done successfully at the output end of the amplifier.

Following calibration, weights were applied and corresponding counts were observed on the visual display of the recorder. After two months operation, this procedure was again implemented, resulting in what appears to be an overall error of 1%. For example, for a total weight application of 300 lb. (136.36 kg), the recorder may indicate 303 lb. (137.73 kg). However, for small weights of 0.4, 1, 2, 5, and 10 lb (0.82, 0.455, 0.909, 2.273, 4.545 kg), corresponding counts of 1, 2, 4, 10, and 20 were observed. Using this same procedure without the stock tank cover during windy conditions confirmed the capability of the recorder to average out wind effects during the 1-min integration period.

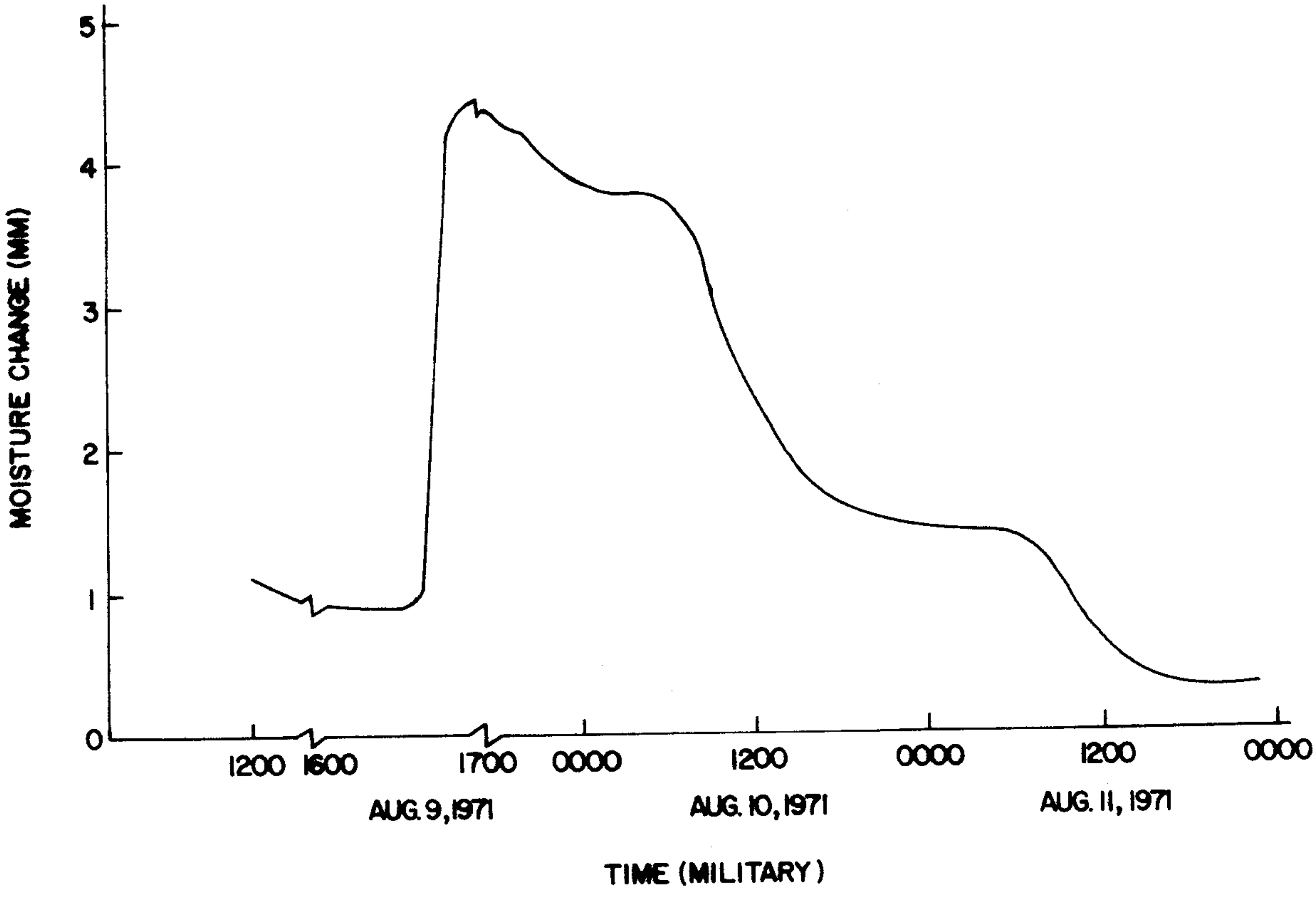

Fig. 6. Rainfall-evaporation curve from Pawnee Site lysimeter.

CONCLUSIONS

Initial planning and design work began in June 1969, and the calibration was concluded 2 years later. Nearly 1 year was used in finalizing a design, purchasing, and securing logistics.

Costs

Total costs of materials, equipment, and rentals was $14,000 of which the major portion was attributed to the scale ($3,060), steel ($3,920), drilling services ($2,450), crane rental ($740), conveyor and jack rental ($810), load cell ($500), concrete ($400), power supply and amplifier ($480), and standard weights ($330). Labor costs involved one full-time engineer-constructor for 29 months and an electronics-construction technician for approximately 5 months total time. Overall cost of the lysimeter, including overhead, totaled $51,500.

Results

Moisture conditions within the soil container are just beginning to approach corresponding conditions in the surrounding natural soils. Application of large amounts of water to the soil core during construction resulted in moisture content values within the core being more than twice those found in the surrounding soils. Visually, this was demonstrated by the more luxuriant plant growth upon the core. A vacuum was applied to the drainage tube for several weeks to accelerate drying.

Data manipulation to date has been in the form of time-moisture change curves (Fig. 6 and 7), primarily to observe the behavior of the lysimeter. These curves illustrate the sensitivity and typify this transducer system.

The stable behavior observed thus far coupled with the unique undisturbed features of the lysimeter, indicates optimism. The lysimeter should contribute substantial input into evaluating the energy budget of the prairie grassland.

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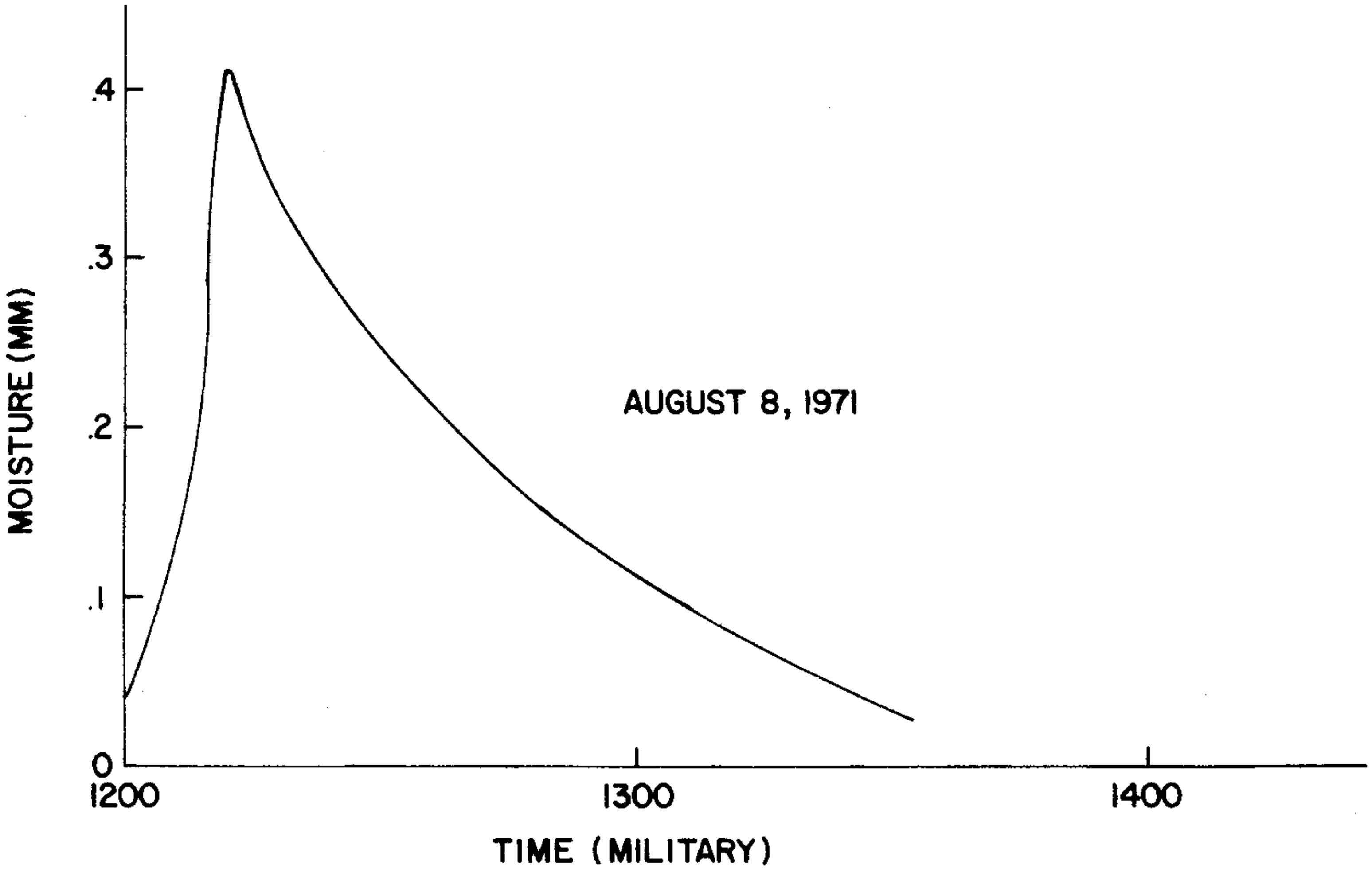

Fig. 7. Typical rainshower as depicted by the Pawnee Site lysimeter.

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