Automated Rainout Shelter for Controlled Water Research

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Abstract

An automated rainout shelter was constructed at the Northern Great Plains Research Laboratory, Mandan, N. Dak., for use in conducting controlled water research to gain a better understanding of soil-plant-water relationships. The design and construction criteria were developed to accommodate many components that were commercially available. The primary components are: (1) foundation, (2) steel I-beam rail, (3) roller mechanism, (4) rainout shelter structure, (5) drive mechanism, (6) electrical control system, and (7) irrigation system. Wind, temperature, and precipitation sensors activate movement of the shelter to cover a plot area 11.5 × 30.3 m (38 × 100 ft), resulting in a modification of the selected environmental conditions. After inactivation of the sensors and a time delay, the rainout shelter automatically returns to its rest position, ready to repeat its cycle when the sensors are reactivated.

Water frequently limits grass establishment and crop yield in the semiarid northern Great Plains. However, field research has not been able to adequately quantify the effect of water stress on plant growth at critical growth stages from seedling establishment to maturity. Any large or untimely precipitation event will confound or negate the results of such field experimentation. Rain shelters or rainout shelters have been designed to overcome this problem. The first rainout shelter was built in 1962 at Iowa State University (Horton 1962). Early shelters were small in size and required trade-offs between plot size and replication of treatments as well as limiting the size of farm equipment that could be used to apply cultural practices. Since then, several designs have been developed and larger shelters have been built and were reviewed by Upchurch et al. (1983).

Rainout shelters have provided a mechanism to bridge the gap between greenhouse or growth chamber and field experiments by modification of the field environmental conditions, primarily precipitation. The purpose of this paper is to describe the development and function of this automated rainout shelter for controlled water research at the Northern Great Plains Research Laboratory, Mandan, N. Dak.

Development and Construction

The shelter was constructed on a Parshall fine sandy loam (coarse-loamy, mixed *Pachic Haploborolls*) with 0–2% slope. This soil is deep (1.6 m +), moderately well to well drained, with moderately rapid permeability, and is moderately extensive in western North Dakota, northwestern South Dakota, and eastern Montana. The primary crops grown on this soil are small grain, oilseed crops, corn, domesticated grass, and alfalfa. Native vegetation found on this soil is a mixture of medium and short grasses.

Construction orientation was in a northwest to southeast direction, parallel to the prevailing winds. This orientation was used to reduce wind resistance, minimize shadow effects, and facilitate winter snow management.

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The shelter covers a plot area of 11.5 × 30.3 m (38 × 100 ft.), an area of 348 m² (3800 ft²). The total rail length is 69.7 m (230 ft) on each side of the shelter. This allows 30.3 m (100 ft) for the building at rest, a 9.1 m (30 ft) buffer zone between the building at rest and the active plot area, and 30.3 m (100 ft) for active plot area. The height clearance within the rainout shelter is 2.5 m (8.3 ft). This allows for research on taller crops such as corn or sunflowers and for the use of most farm equipment for applying cultural practices. Costs for the construction of this rainout shelter, including the travelling irrigator, were $81,700.00. This figure does not include salary time spent on the project by employees of the Northern Great Plains Research Laboratory, which is estimated at 1,120 work hours for an additional cost of abour $12,771.00.

The southeast end of the rainout shelter consists of nondisturbed soil which will be used for most of the research work. The northwest end can be used for disturbed soil studies or, by excavation and back filling, different textured soil materials could be studied. The rest and active shelter positions can be reversed by switching the electrical controls.

The shelter was designed and constructed using many components which are readily available to the building trade. The principal parts of this rainout shelter are: (1) foundation, (2) steel I-beam rail, (3) roller mechanism, (4) rainout shelter structure, (5) drive mechanism, (6) electrical system, and (7) irrigation system. Design of this rainout shelter considered the variable and sometime severe environmental conditions experienced in the northern Great Plains. This was important since a shelter that would be durable and workable for many years was needed to justify the construction cost. The components were designed for expected wind and snow loads, frost depth, and other adverse environmental factors. No special fixtures to shed water away from the shelter were incorporated and do not appear needed. However, the option to install rain gutters and special drainage is available. Fans for ventilation of the shelter while over the plots were considered and can be installed. At this time, no need for ventilation above that which is currently possible with door operation and the time plots are covered appears needed. The shelter was not designed for winter operation because of ice and snow buildup on the tracks and the extreme stiffness of this equipment at below zero temperatures. To design any shelter for operation during the winters experienced in the northern Great Plains appears unfeasible. Other options for snow management such as snow removal, leaving the plots covered over winter, or documenting soil water from snowfall are possible.

Foundation

Because soil freezing is common in North Dakota, footings, 0.3 m thick × 1.1 m wide × 69.7 m long (1 ft × 3.5 ft × 230 ft), of concrete support footings with steel bar reinforcement were poured at a depth of 1.5 m (5 ft) on each side of the structure, well below the normally expected frost depth (Fig. 1, A). This type of footing was critical to insure stability and straightness of the steel I-beam rail. Reinforcement rod from the footings extended into a 0.25 m wide × 1.36 m high × 69.7 m long (10 in × 4.5 ft × 230 ft) concrete wall set 10.2 cm (4 in) in from the inside of each footing (Fig. 1, B). This provided a reversed L shape foundation to give added strength against the outward pressure that would be exerted

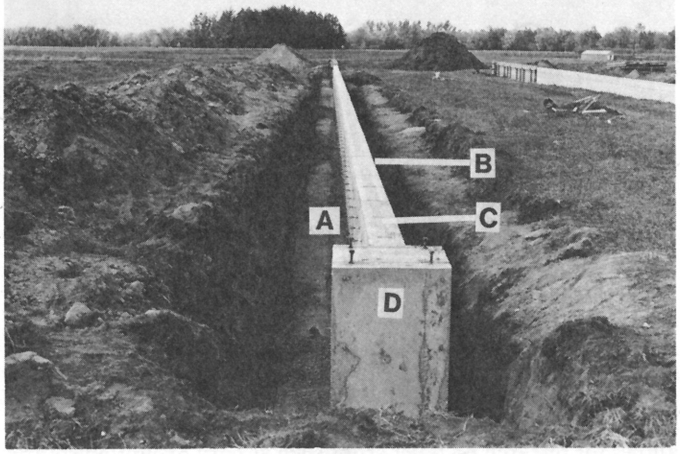

Fig. 1. *Foundation for rainout shelter. (A-footing; B-wall; C-T iron, and D-pillar)*

by the rainout structure. No tie-rods were placed between the footings and walls on either side of the shelter, thus leaving soil in the covered area clear of structural material.

A T iron, 0.64 cm thick and 7.6 cm wide × 69.7 m long, (1/4 in and 3 in × 230 ft) secured with 25.4-cm (10 in) looped reinforcement rod was imbedded in the top of each wall to provide the mechanism for later attaching an I-beam rail (Fig. 1, C). To insure levelness, the top of the T iron was surveyed in when the wall was poured. A pillar of concrete 1.7 m high and 0.8 × 0.8 m square (5.5 ft high × 2.5 ft square) with reinforcement rod extending into the wall was poured on each end of the footings and walls, to provide a platform for a protective abutment around the rainout structure (Fig. 1, D).

I-Beam Rail

The rail consists of a 12.7 cm × 22.1 kg/m (S 5 in × 14.75 lb/ft) I-beam (Fig. 2 D) welded on top of square tubing 7.6 cm square and 0.64 cm thick (3 in square and 1/4 in thick) (Fig. 2 C). On the

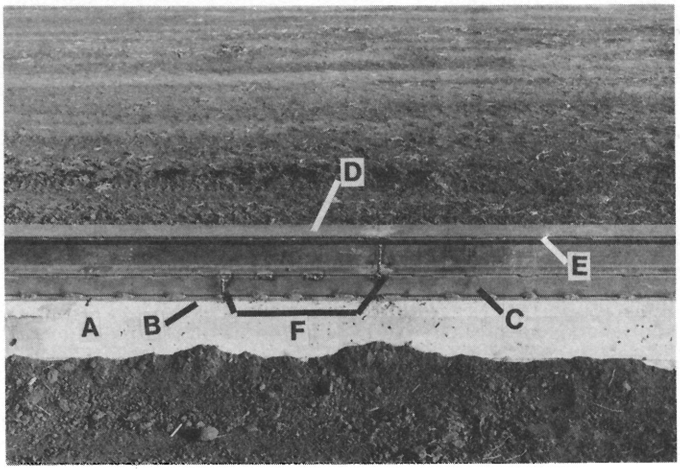

Fig. 2. *I-Beam rail for rainout shelter. (A-wall; B-top of T iron; C-square tubing; D-I-beam; E-strap metal; and F-splice overlap)*

top of each side of the I-beam, a 0.95 cm thick × 1.91 cm wide × 69.7 cm long (3/8 in thick × 3/4 in wide × 230 ft long) strap metal strip (Fig. 2, E) was welded to reduce the free play between the vertical rollers and the top of the I-beam rail. The manufacturer assembled and supplied the I-beam, square tubing, and strap metal in 6.1 m (20 ft) lengths with a 40.6 cm (16 in) offset (Fig. 2, F) to provide strength to the joints. Each section of rail was placed on top of the T iron in the foundation wall (Fig. 2, B), aligned, and welded into place. Joints between square tubing and rail sections were welded together and ground smooth. The rail and square tubing (69.7 m; 230 ft) were attached on both foundation walls. A 2.54 m thick, 20.32 cm wide, and 30.48 cm long (1 in thick, 8 in wide and 1 ft long) steel plate was welded to the end of each rail to prevent the roller mechanism and rainout shelter from rolling off the end of the I-beam rail. The completed I-beam rail and square tubing assembly was cleaned with a wire brush before applying primer and paint coatings for rust protection.

Roller Mechanism

The housing for each of the 12 roller mechanisms (Fig. 3, C) was constructed from pre-cut 1.27 cm (1/2 in) thick steel. Four 12.7-cm

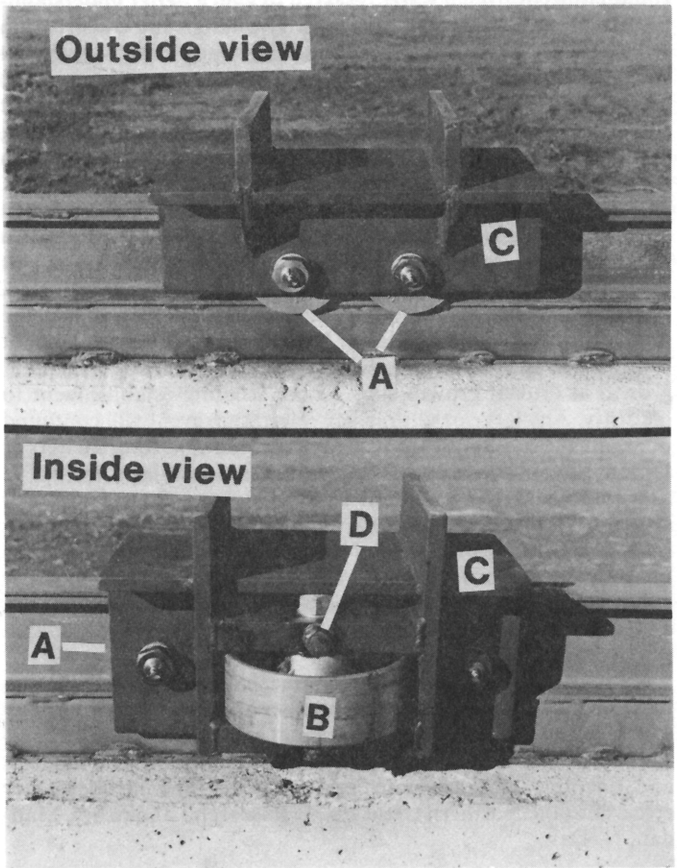

Fig. 3. *Roller mechanism for rainout shelter. (A-vertical rollers; B-horizontal roller; C-housing; and D-set screws)*

(5 in) flanged rollers per housing, 2 on each side of I-beam, carried the vertical weight (939 kg/roller mechanism; 2,069 lb/roller mechanism) on each structural column (Fig. 3,A). Each roller had a sealed double ball raceway bearing and a 2.54 cm (1 in) diameter axle and was rated for 2,902 kg (6,399 lb) capacity. If this mechanism were redesigned, only 1 roller would be used on the outside of the I-beam rail for a total of 3 vertical rollers per housing so that the housing would be self leveling. One 7.6 wide × 20.3 cm diameter (3 in × 8 in) horizontal roller (Fig. 3, B) rated for 2,041 kg (4,500 lb) runs on the inside of the I-beam rail to offset the outward pressure exerted by the rainout shelter structure. This roller was mounted in a slot on the housing and equipped with set screws for lateral adjustment (Fig. 3, D).

Rainout Shelter Structure

The structure is a standard 12.1 m wide × 30.3 m long × 3.0 m high (40 × 100 × 10 ft) steel and metal frame building with a total weight of 11,264 kg (24,833 lb). The bottom girt along each side of the building was replaced with a factory designed I-beam for added strength (Fig. 4, A). The ends of the building were left open. Each

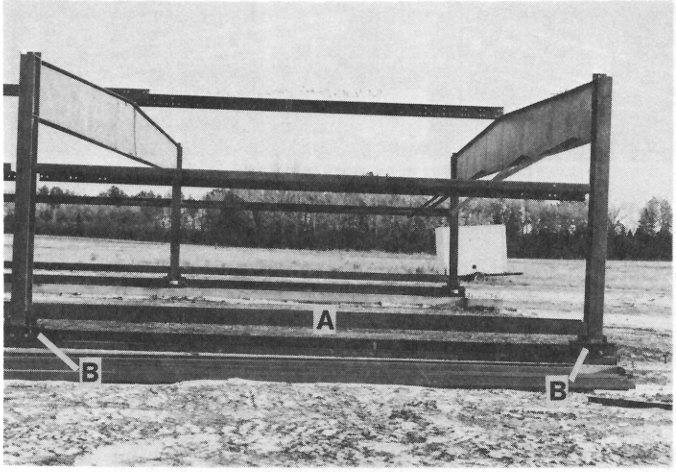

Fig. 4. *Steel and metal frame for rainout shelter structure. (A-I-beam for added strength; and B-columns directly welded to roller mechanism housing)*

column (12) of the building was welded directly to the top of the roller mechanism housing described above (Fig. 4, B). The steel and metal frame was covered with white siliconized corrugated steel siding fastened by Type B self-drilling carbon steel screws. These screws were later replaced by bolts and nuts because the screws tended to loosen from the vibration of the moving shelter. Airplane hangar bi-fold aluminum doors 11.6 m wide × 3.0 m high (38.2 × 10 ft) were installed on each end of the building. Each end door is driven by a 0.56 kW (3/4 hp) electric motor. When open, door clearance is equal to the height of the rafters of the building, approximately 2.5 m (8.3 ft). The aluminum frame doors were covered with the same steel siding as the building (Fig. 5).

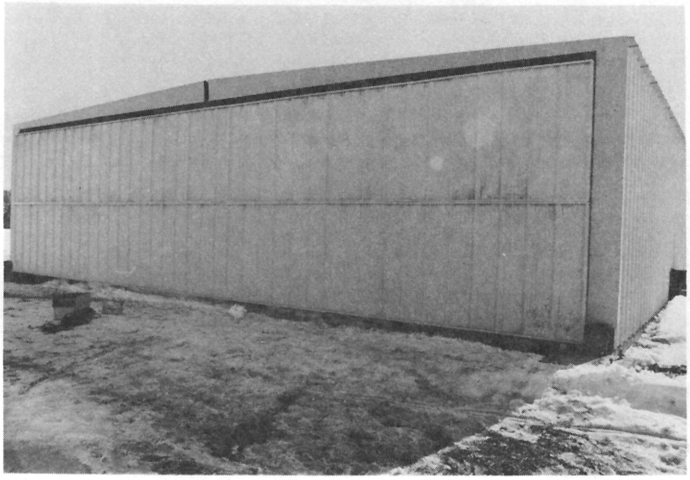

Fig. 5. *Rainout shelter structure showing steel siding and bi-fold door.*

Drive Mechanism

The shelter is moved by two independent, twin-drive mechanisms, one on each side of the building. Two 1.27 cm thick (1/2 in) steel plates (Fig. 6, E) provide the structural support for each drive unit. These plates were placed on the second building column from the NW end of the building (Fig. 6, F). This structure supports the 6.35 cm diameter (2.5 in) drive shaft (Fig. 6, D), the bearings (Fig. 6 C,), the cyclodal tooth sprocket (Fig. 6, A), and provides for the

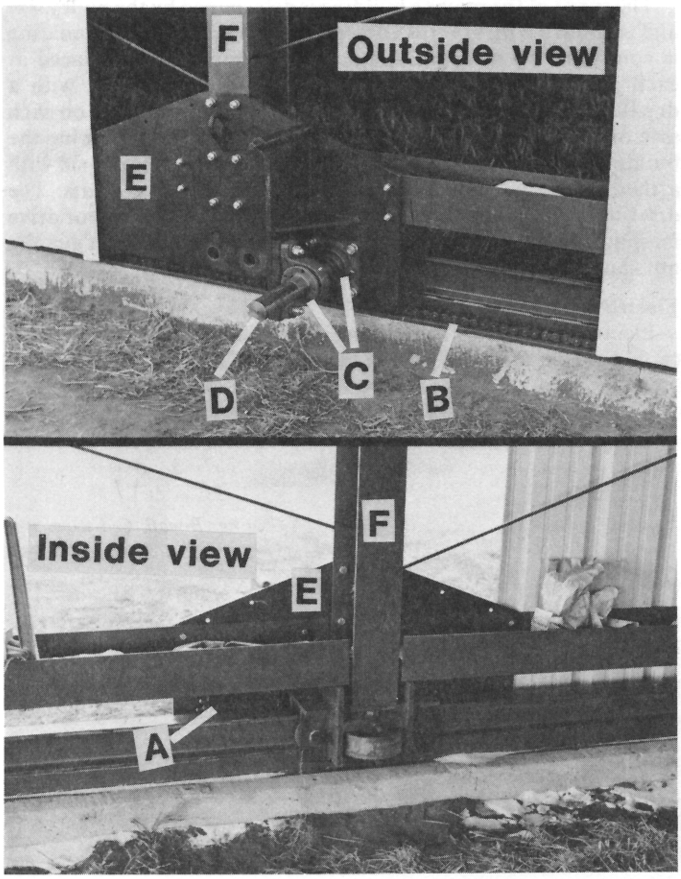

Fig. 6. *Support structure for drive mechanism before inside metal plate was attached for strength. (A-cyclodal tooth sprocket; B-roller chain; C-bearings; D-drive shaft; E-steel plate; and F-second column from NW end of rainout shelter)*

attachment of the motor and shaft-mounted gear box assembly on each side of the building. The cyclodal tooth sprocket drives the building, guiding on a free floating size 100 high speed standard roller chain placed along the outside of the I-beam rail and anchored at both ends with tension adjustment (Fig. 6, B). This results in a rack and pinion drive mechanism. The cyclodal tooth sprocket is driven by a shaft mounted gear box (Fig. 7, A) with a 2.24 kW (3 hp) electric motor (Fig. 7 C). Power is transferred to a Q1 × 2.54 cm (1 in) × 1.27 cm (1/2 in) two-grove pulley by 2 V-belts (Fig. 7, B) which drive a gear box.

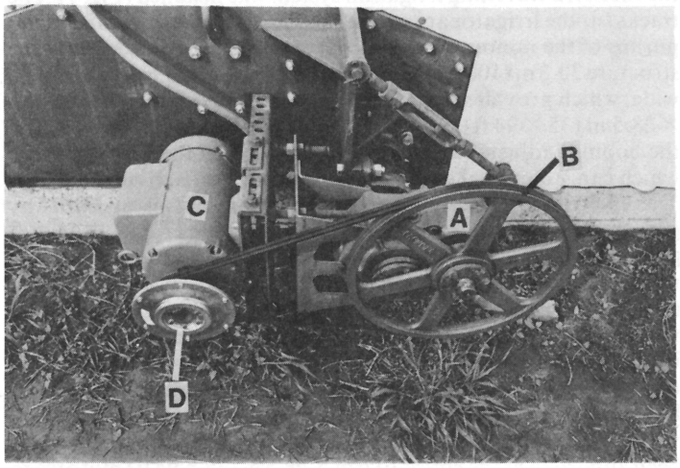

Fig. 7. *Drive unit for movable rainout shelter. (A-gear box; B-pulley; C-electric motor; and D-dry-fluid clutch unit)*

The speed of the moving building is determined by the pulley size and is about 0.3 m/s (1 ft/s). The distance travelled by the building is controlled by mechanically activated limit switches placed at each end of one I-beam rail. Each motor is equipped with a dry-fluid clutch unit (Fig. 7, D) to synchronize the motors on each side of the building each time the motors start, thus allowing the building to pull evenly. Each dry-fluid clutch unit is equipped with a thermal cutout switch in case the clutch unit over-heats. The dry-fluid clutch units are crucial to the 2 independent motor drive mechanisms involved in moving the shelter. Pulley and belt guards, not shown in Figure 7, have been installed for safety.

Electrical System

Electrical power to the building is supplied through an electrical cable held on a spring loaded take-up reel (Fig. 8, A). This reel

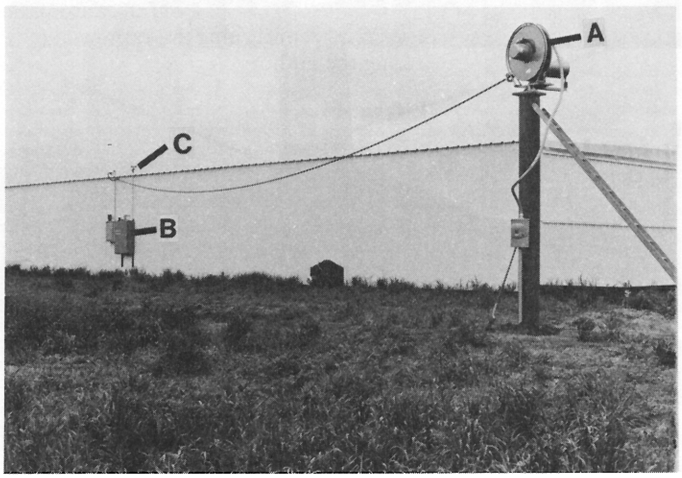

Fig. 8. *Electrical system for rainout shelter. (A-takeup reel; B-electrical distribution box; and C-weather sensors)*

supplies cable or takes up cable depending on the position of the structure. Power is distributed through a weatherproof electrical box (Fig. 8, B) attached to the structure. Wind and rain conditions are determined by sensors on top of the rainout structure (Fig. 8, C). A temperature sensor is provided at the electrical box. These sensors are commercially available greenhouse controls. Circuitry from sensors to building- and door-drive motors complete with limit and time-delay switches were developed to provide for total automation. Manual override is provided for all functions.

Irrigation System

To accurately and uniformly apply water for experiments under the shelter, a travelling irrigation system was installed (Fig. 9). The tracks for the irrigator are secured to the overhead steel rafters and purlins of the rainout structure and extend the entire length of the structure 30.3 m (100 ft). The boom on the irrigator is 10.6 m (35 ft) wide, which provides for an irrigated area under the shelter of 10.6 × 28.5 m (35 × 94 ft) (302 m^2 or 3,290 ft^2). The length of travel of the boom is adjustable by positioning stops on the irrigator track which can stop travel of the irrigator or turn off and on the water. The 10.6 m (35 ft) boom can be zoned into halves or thirds by proper valve selection to irrigate 2 plots 5.3 m (17.5 ft) wide or 3 plots 3.5 m (11.7 ft) wide. This allows for plot selection under the rainout shelter of various sizes, smallest being 3 m wide, 3 m long (10 ft wide, 10 ft long) and the largest 10.6 m wide and 28.5 m (35 ft wide by 94 ft long). The size of the plot that can be used and irrigated by the boom irrigator is determined by the number of replications and treatments desired. Water application rate applied by the boom irrigator can be controlled by nozzles and the speed at which the irrigator travels. In operation, 2.54 cm (1 in) of water has been applied over the entire 10.6 m × 28.5 m (35 × 94 ft) plot area in 3 hr. Application rate varies with the size of the plots and the

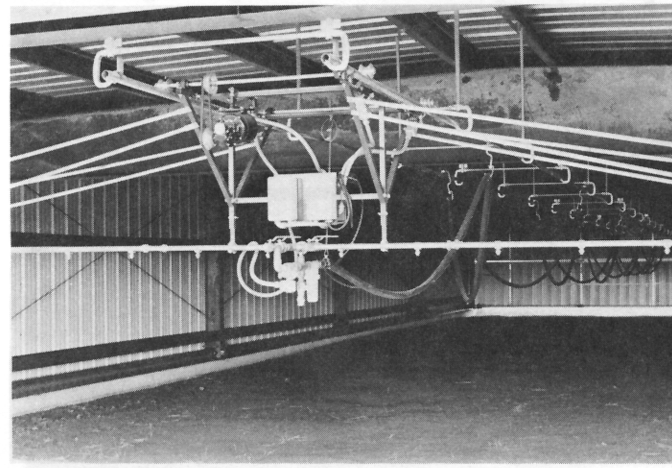

Fig. 9. *Travelling irrigation system in rainout shelter.*

distance the boom irrigator must travel. The amount of water desired is determined in total centimeters per area. This is converted into liters (gallons) of water needed. An electric flow meter measures the amount of water applied to the plot and automatically shuts off the water when the proper amount has been applied. Simulated rainfall at moderate to low intensities is applied with the shelter over the active plot area without interference from wind. Such application of water is hoped to be representative of natural rainfall which occurs during overcast skies and periods of reduced solar radiation.

Function of Rainout Shelter

Wind speed, high or low temperatures or precipitation sensors serve as the activation device to initiate movement of the rainout structure (Fig. 10). Any one or all sensors may be used at any given

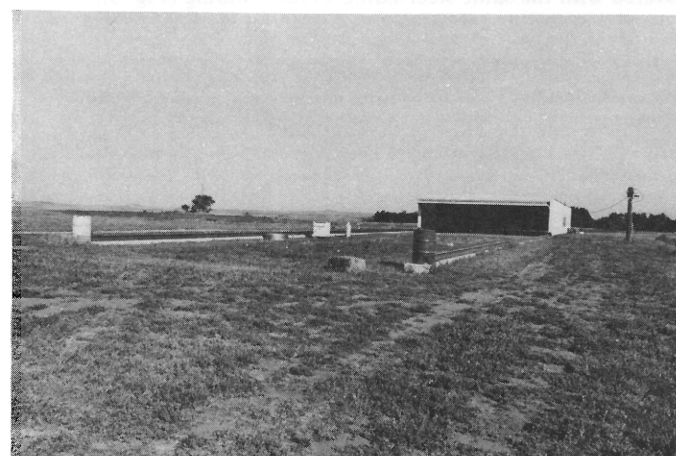

Fig. 10. *Completed rainout shelter in rest position. Active plot area is in the foreground.*

time. When the selected wind speed, temperature or precipitation occurs, the sensors output a low voltage current that activates a relay which in turn starts the electric motors. The shelter is moved from its rest position to a position over the active plot area at the speed of 0.3 m/s (1 ft/s). From the time of activation, the shelter moves from rest to cover position in about 130 s. When the limit switch is tripped at the end of the I-beam rail, the electrical power is turned off, which stops the shelter movement. Because high winds which frequently accompany summer thundershowers increase the inertia of the moving building, heavy duty coil springs were installed at the ends of each rail to cushion the impact of the building at the end of travel. A force of 916 kg (2,020 lb) as measured by a spring scale is required to start movement of the rainout shelter in the rest position. The building and roller mechanisms contribute 680 kg (1,500 lb) of the total force and the dry-fluid clutches and gear boxes provide 236 kg (520 lb) braking protection when the building is in the rest position. A time delay switch, adjustable from 0 to 60 min, keeps the shelter over the plot area for the specified time if the sensors are not activated. After the desired time delay, and if the sensors are not activated, the motors reverse and the shelter returns to the rest position. Another time delay switch, adjustable from 0–30 min, is activated when the shelter returns to the rest position. As soon as the specified time elapses, the shelter is ready to move again, but will remain in the rest position until the sensors are activated by the desired environmental condition. The time delay switches were added to provide time control when environmental conditions are rapidly fluctuating, otherwise the shelter would be activated and inactivated resulting in erratic movement over the plots. A total of 5 mm (0.22 in) of natural rainfall was measured at a central point under the shelter during the 1982 season. This rainfall (an average of 0.5 mm/event; 0.02 in/event) was received during the closing operation of the shelter.

The motor driven bi-fold doors can be set to remain open all the time or to open automatically when movement of the shelter begins. After the building has covered the active plot area, the doors automatically close. The lead door must be open during shelter movement to prevent damage to research instruments or the test crop. Each door can be operated separately or in unison at any time. In general operation, both doors open and close automatically at the start and stop of movement of the rainout shelter. With both doors open, less wind assistance or resistance exists during shelter movement.

By the sequence just described, this rainout shelter can be used to modify the field environment of wind, temperature, and precipitation on the active plot area with manual, partial, or fully automatic control. More detailed information concerning this rainout shelter can be obtained by contacting the authors.

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