EVALUATION OF SURFACE AND SPRINKLER IRRIGATION SYSTEMS ON THE SEEDSKADEE DEVELOPMENT FARM

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SWC Research Report # 414

Northern Plains Branch
Soil and Water Conservation Research Division
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TABLE OF CONTENTS

Page

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E. Gordon Kruse and H. R. Haise[2]

During 1965 several areas of the Seedskadee Development farm located 40 miles northwest of Green River, Wyoming, were developed to study various methods for irrigating marginal lands (class 3 and 4 complex) situated on first terrace soils of the Green River and a border irrigation system of class 2 land situated on the second terrace adjacent to the development farm proper, Fig. 1. One of the major objectives of the study concerned the development and evaluation of automated irrigation systems to improve irrigation water application efficiency and at the same time reduce irrigation labor requirements.

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[1] Contribution from the Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with University of Wyoming Agricultural Extension Service and U.S. Bureau of Reclamation.

[2] Agricultural Engineer and Research Soil Scientist, respectively, USDA, Fort Collins, Colorado.

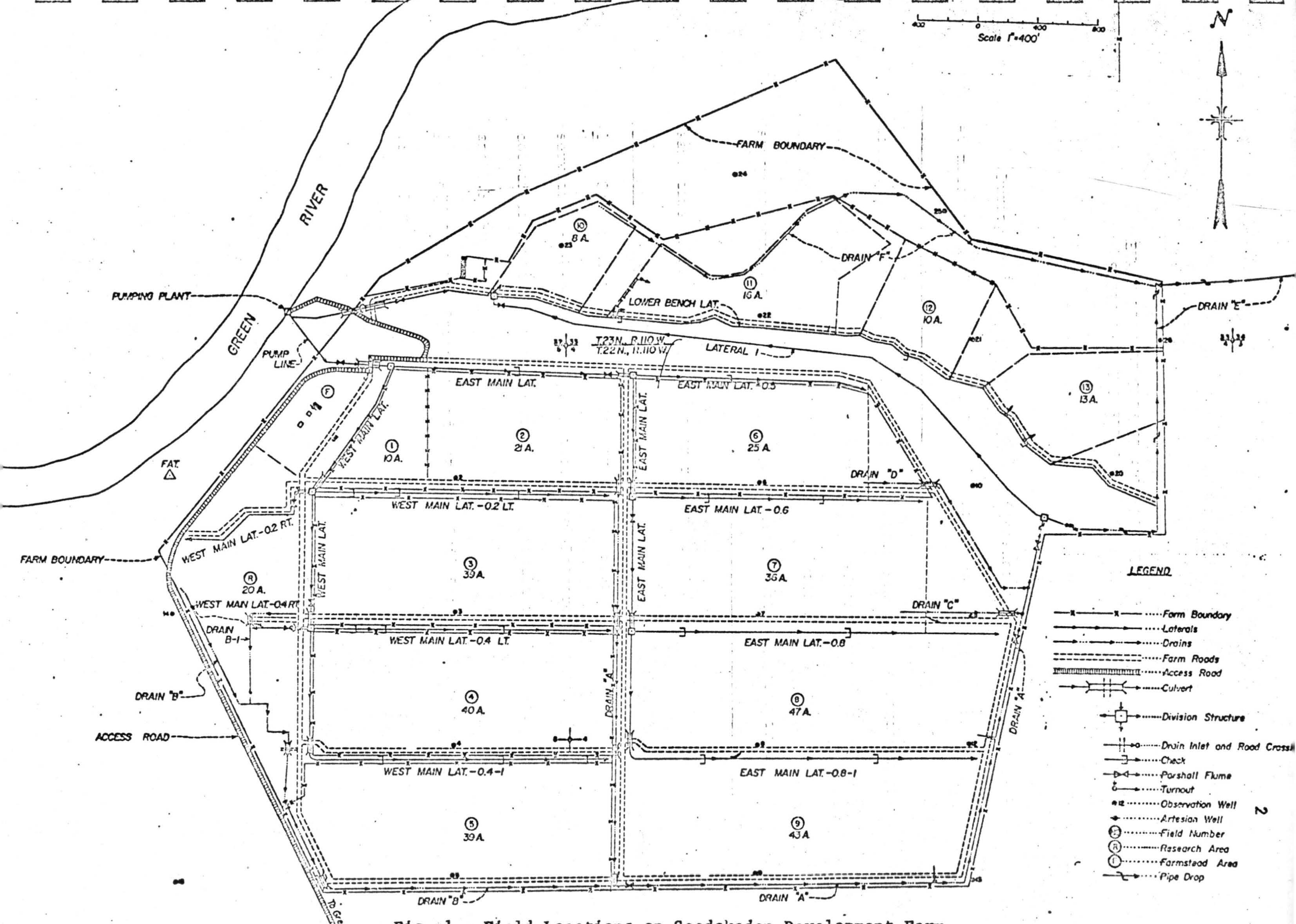

Fig. 1.--Field Locations on Seedskadee Development Farm.

Research Area - Lower Bench

The need for the study of lower bench areas and the objectives of the research were stated as follows in the ARS outline for the study:

Need for Study:

> The purpose of research on the lower bench lands of the Seedskadee Development Farm is to determine the economic feasibility of applying irrigation water to the shallow soils existing there for the purpose of providing pasture for livestock. The labor required for irrigation should be minimized by the use of simplified systems and automatic devices wherever possible. Feasibility of irrigating this area is also limited by the fact that gravity water applications will have inherently low efficiencies and only 3.25 acre-feet of water will be available for each acre of land during the growing season. If irrigation can be shown to be economically feasible on these soils, an additional 10,000 acres of land can be added to the Seedskadee Irrigation Project.

Objectives:

> Four methods of irrigation will be compared in terms of:
>
> 1. Land preparation and equipment cost.
> 2. Labor requirements
> 3. Water requirements
> 4. Crop yields.

Land preparation was limited by the very shallow soils on much of the lower bench area, which severely limited allowable cuts during land forming.

Discussions of land preparation, irrigation methods and results for each of the four lower bench fields follow.

Field 10, Border Dike Irrigation

Land Preparation and Seeding: Field 10 on the Lower Bench consisted of guide border strips approximately 20 feet wide, oriented in a general north-south direction. A motor patrol was used to construct dikes 12 inches high with 1.5 to 1 side slope. Each border strip had zero cross slope. The longitudinal slope was to follow that of the existing ground surface so as not to have cuts in excess of 0.2 foot except where necessary to remove hummocks. Borders 20-29 were crossed by a ridge about 350 feet downfield which at the extreme was about 1 foot above the tops of the turnouts. Some of the first borders on the west side had reverse grades on the lower ends of the borders and these were removed by the dozer and blade. On June 26, 1965, a grass-legume mixture was seeded and watered by surface application techniques. The lack of an established grass stand initially created problems of soil erosion. Furthermore, some borders still had a reverse slope and had to be re-levelled, using a crawler tractor with blade. The borders didn't irrigate as well as hoped because the water would concentrate in narrow streams when flowing from the relatively flat portions of the upper ends of the borders onto the steeper gradients and begin eroding a channel in the sandy soil. Existing high spots and side slopes concentrated the flow and accelerated erosion. Some cross-field dikes were built in the borders to slow the rate of advance and to get coverage of high spots. The crop stand on the field was fair except on the head ends of borders 27 and 28 which may have suffocated by excessive ponding. Construction of some borders left adverse gradients just downstream of the turnouts, causing overtopping of the dikes and making irrigation generally difficult. Fill should have been placed at the head ends of these borders to prevent ponding.

Automation: Each 8-inch turnout on field 10 was fitted with a "lay-flat" butyl rubber pneumatic valve.[1/] On a section of the field where one turnout had been provided for each two borders, a 10-foot butyl rubber "sock" was attached to the downstream end of the turnout pipe to direct water to one border or the other. A polyethylene air line (not buried) was run to the field from the air compressor on the upper bench. Wires from a "tone-telemetry" transmitter at the compressor site were enclosed in this air line.

Prior to the first trial of the lay-flat valves on this field, cattle were driven over the exposed portion of the compressed air line leading to the field. Before this leak was found and repaired and because of an uninspiring performance of a similar system on the upper bench research area, the automatic irrigation system on field 10 was abandoned.

The concept of using only one turnout for each two borders, switching flow from one to the other with a butyl rubber "sock," has worked satisfactorily. Use of this concept may help reduce construction costs on similar border systems. However, the border widths were only 20 feet. On wider borders, the longer sock required to apply water at the center of each border would be both more expensive and more difficult to handle.

Field 10 was irrigated manually during 1966 because of the problems with the automatic system discussed earlier. Eight irrigations were applied with a labor requirement of two-thirds man-hour per acre per irrigation. Volumes of water for two of the eight irrigations were

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[1/] Haise, H. R., E. G. Kruse, and N. A. Nimick - Pneumatic Valves for Automation of Irrigation Systems. Agricultural Research Service, USDA, ARS 41-104, July 1965.

measured and indicated gross applications of approximately 2 surface inches. In 1967, field 10 was irrigated by University of Wyoming personnel and ARS kept no records.

Harvesting: The narrow (20-foot) widths of border on this field greatly hampered harvesting. Only one swather width could be cut from each border. In 1967 livestock grazed the field, allowing more complete utilization of the forage produced. Future borders should be laid out with a width between dikes equal to some even multiple of the width of available harvesting equipment.

Field 11, Contour Ditch

Land preparation of field 11 consisted of clearing sagebrush and other vegetation, followed by rough grading to remove hummocks. Three relatively large high areas that could not be watered without running stub ditches remained within the borders of the field. These areas were seeded and with the exception of sprinkling to establish stands of grass and alfalfa were not watered during the first two years of operation.

Two contour ditches were provided for irrigation of field 11. The first followed along the south field boundary. The second ran along the crest of a ridge in the center of the field.

Automation: A modification of the Farmhand Irrigator was constructed for use in irrigating field 11 from the contour ditches. This irrigator supplied by the manufacturer, is supported by a tricycle-like carriage with two drive wheels that straddle the ditch and a bullet shaped skid in front that follows the bottom of the ditch to guide the machine. The irrigator is powered by a small gasoline engine. A canvas dam, mounted at the back of the irrigator, checks water behind the machine and causes water in the ditch to flow over the banks. Land on the downstream side of the ditch is watered as the irrigator moves slowly along the contour ditch. Since water cannot be allowed to overflow ditches with erodable banks such as the ones on field 11, the irrigator was modified to lift water over the ditch banks.

The first modification of the irrigator consisted of mounting a six-inch auger at the rear of the machine. The auger was fitted with piping so that pumped water could be safely released on the downstream side of the ditch bank. Use of the auger required adding a gear box, increasing the engine size and relocating the check dam on the original machine. The modification, after development in the laboratory, was evaluated at field locations near Fort Collins, Colorado and Fontanelle and Pinedale, Wyoming, during the summer of 1965, Fig. 2.

After the power dike was field tested, it was evident that more laboratory research was needed to improve the efficiency of the water auger. Pump efficiency in relation to design of the auger was determined in the laboratory using different lengths of flighting in the auger, different pitch of the flighting, different rotation speeds, and different angles of inclination measured from the horizontal.2/

The modified power-dike was used for several irrigations of field 11 in 1966. The primary operating difficulty was caused by the auger picking

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2/ Rider, Allan R. Pump Characteristics of a Screw Conveyor Used on an Automatic Irrigator. Unpublished M.S. Thesis, Dept. of Agr. Engr., CSU, June 1966.

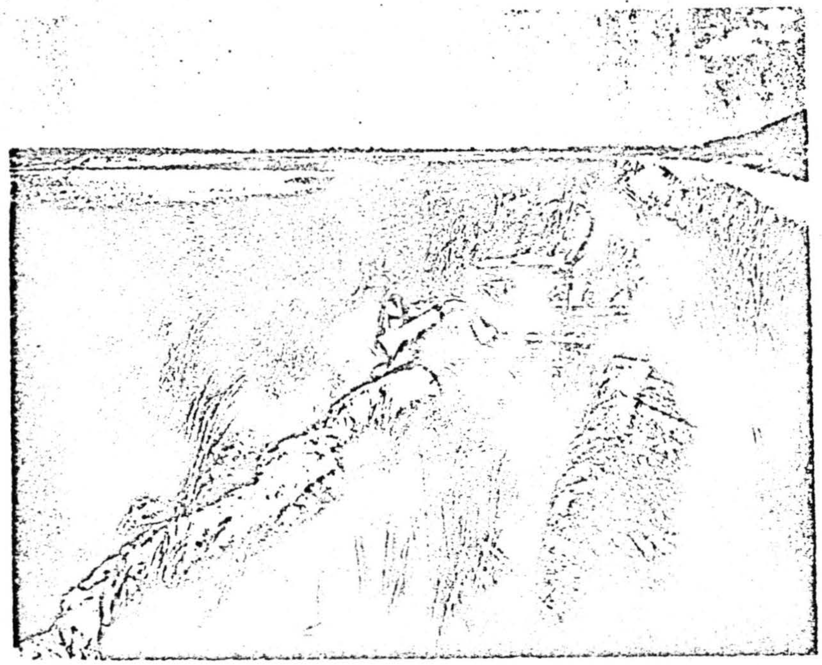


Fig. 2.--Farmhand irrigator, modified to auger water over one ditch bank as it propels itself along the ditch. A flexible dam, fastened to the front of the irrigator, checks water to supply the auger. A small gasoline engine supplies power to propel the machine and operate the auger.

up small stones from the bottom of the irrigation lateral. These stones wedged between the blade and housing of the auger with such frequency that constant attention was required to keep the machine running. A screen over the auger intake partially solved this problem. There was also some difficulty in keeping the machine in alignment on the ditch banks. If one of the drive wheels started to roll into the ditch, it was difficult to correct. To do so, it was necessary to stop the flow of water into the irrigation lateral.

The dam on the power-dike did an adequate job of checking water in the lateral. A small, but inconsequential, amount seeped under the dam and flowed on down the ditch. The auger pumped about one cfs which was barely adequate to irrigate field 11. Additional gearing to slow machine travel would be helpful in attaining more efficient irrigation. With the added weight of the modified machine, it was necessary to add chains to the drive wheels. Even so, slippage was considerable, sometimes greater than 20 percent.

The total irrigation water applied to field 11 in 1966, 513,920 ft.^{3}, represents a depth of 13.4 inches on the 63 percent or 10.5 acres that were covered with irrigation water. This water was applied in seven irrigations, for an average gross application of 1.9 inches.

The total amount of water received by field 11 during the period May 15 to September 15, 15.3 inches (13.4 by irrigation plus 1.9 by rainfall), was not enough for maximum production on the field. There was no runoff from field 11. Irrigation water collected in some low spots and these low spots showed the best crop growth on the field.

This field was originally served by two contour ditches which allowed about two-thirds of the field area to be inundated during irrigation. In 1967, additional stub ditches were run to small high areas on the field, allowing greater coverage. Also, in 1967 field 11 was pastured only. Thus the additional ditches did not pose an inconvenience during harvesting.

Good crop growth on field 11, relative to other lower bench fields,[1/] is due in large measure to its location, adjacent and parallel to the scarp separating upper and lower benches. Thus, a larger portion of this field consists of Unit 4 soils (Binschadler, 1964[2/]) which are the deepest on the lower bench area and which receive supplemental water from lower bench lateral seepage.

Field 12, Side Roll Sprinkler System

Field 12 was prepared for sprinkler irrigation by removing the native vegetation with scrapers. Some topsoil was removed with the vegetation, however, and the rows of topsoil that were piled up by scrapers were evident in the uneven appearance of the crop stand after seeding.

[1/] See cover photograph, S. D. F. Progress Report, 1964-1969.

[2/] Bindschadler, H. Soil Survey Report - Seedskadee Development Farm. Unpublished Report, Soil Conservation Service, USDA, Laramie, Wyoming, August 1964.

Automation: A side-roll, engine move sprinkler system was assembled on field 12 after seeding was completed in July 1965, Fig. 3. Water was supplied from the lower bench irrigation lateral by a centrifugal pump powered by a four-cylinder, LP gas engine. The system was designed for close nozzle spacing because of the windy conditions that commonly occur in the Seedskadee area. Sprinkler heads were spaced every 30 feet along the lateral. The lateral was moved 48 feet at each setting.

Aerial photographs of field 12[1/] indicate parallel rows of alternates good and poor crop growth, the rows running parallel to lateral of the side-roll sprinkler. At first glance, then, this variation might be thought due to nonuniform distribution of water from the side-roll sprinkler, as the sprinkler lateral was positioned parallel to the stripes of good growth. However, field 12 was irrigated with 13 sets of the sprinkler lateral and only 9 growth stripes appear on the photograph. It is concluded that the redistribution of top soil during the clearing and windrowing of sage on field 12 might possibly have caused the growth variation observed.

In 1965 and early 1966, only one nozzle was used in each sprinkler, giving an application rate of 0.37 inches per hour at an operating pressure of 60 psi. Prior to the July 22, 1966, irrigation, a second nozzle was added to each sprinkler head, increasing the application rate to 0.52 inches per hour.

See cover photograph, S.D.F. Progress Report, 1964-1969.

Fig. 3.--Side-roll sprinkler lateral in operation on field 12. The lateral, 660 feet long, was capable of applying water at a rate of one-half inch per hour.

In 1966, 9.6 inches of water was applied to this field between 6/23 and 9/11. Two earlier irrigations added an estimated 1.6 inches. Hay production was very poor, 48 bales for the entire field, due to the limited irrigation and the shallow soils.

Field 12 was irrigated ten times in 1967. During the first half of the season, four irrigations totalling about 7.5 inches of water were applied at ten-day intervals. Rainfall supplied an additional 2.5 inches. Thus, about 0.22 inches of water per day was available during this period. This application produced a yield of about 1.4 tons per acre at the first cutting. Following harvest operations, irrigations could not be commenced for 30 days because hay bales were not removed from the field. During this period, most of the available water was depleted from the shallow soil profiles within the experimental site. Subsequent irrigations failed to revive the good alfalfa growth noted earlier. Furthermore, the alfalfa appeared to be under some soil moisture stress part of the time between irrigations from June 22 to August 15. Then smaller irrigations (about 1.5 inches) were applied at average seven-day intervals until the end of the irrigation season. A total of 165.5 acre-inches of water was applied during the 1967 season or 18.4 inches on the 9.01 acres of field 12. By comparison, 16.6 inches were applied by the center pivot sprinkler on the upper bench during 1967,[3/] mostly for use of the oats nurse crop on the field. Applications from the center pivot on alfalfa in 1968 and 1969 were 18.3 and 23.5 inches, respectively; the latter figure representing a 3-cut season.

3/ Barnes, O. K. Seedskadee Development Farm Progress Report 1964-69. Bull. 506, Ag. Ext. Serv., U. of Wyo., Jan. 1970.

The largest individual application to field 12 was 2.36 inches. Assuming an 80 percent application efficiency, the net application was 1.89 inches. Part of a net application this large will be lost as deep percolation on soils that hold only 1.6 inches total available moisture. On the soil areas with available moisture capacities from 2.5 inches to 3.4 inches, moisture deficiencies of 1.9 inches can be allowed to develop without seriously reducing crop yields. An irrigation interval of 8 to 11 days would be allowable for these deeper soils.

The side-roll sprinkler system worked satisfactorily throughout three irrigation seasons. The primary problems which had the effect of increasing labor requirements for the system were:

1. Clogging of sprinkler nozzles and lateral drain valves by pumped sediment. Cleaning nozzles and closing drain valves required considerable operator time whenever the system was moved. If this labor had not been necessary, the system could have been moved from one set to the next in about 10 minutes by two men. A sediment-free water supply or sediment-excluding pump intake is necessary.

2. Mechanical problems with pump and LP gas engine. The problems would not beserious if the location of the system were not so far from dealer's service.

3. After several trips back and forth across the field, the lateral tended to shift laterally, away from the main supply line. This necessitated manual repositioning once during a two-year operating period.

No poor uniformity of application due to wind distortion of sprinkler pattern was visible on field 12. However, such distribution would have been difficult to observe on this shallow, rocky soil if it had occurred.

Also, the lateral did not move under windy conditions when empty. During winter months, the pipe lateral was anchored to a fence at the field boundary.

The original telescoping aluminum pipe sections for connecting lateral to main were replaced by flexible reinforced high pressure tubing. This change greatly reduced the labor requirement for moving the lateral.

During 1966, the labor required to move the sprinkler lateral, averaged 0.24 man-hours per acre per irrigation. In 1967, the recorded labor needed to move the system jumped to 0.7 man-hours per acre per irrigation. Much of the additional requirement was for cleaning sand from sprinklers and drain valves of the system. Much sand had blown into the lower bench lateral, from which water for the sprinkler was pumped, during the winter of 1966-67.

Soil Profiles and Root Depth

In the fall of 1967, pits were excavated at several locations in field 12, on the deep cut areas of field 7 and on the field irrigated by the self-propelled sprinkler. Fig. 4 indicates the approximate locations of the pits on field 12 and Figs. 5 through 12 are photographs of soil profiles and root development. Fig. 13 is typical of crop growth on the field and materials removed from the pits.

Note that deeper soils occurred along the south edge of this field as a result of outwash from the bluff separating the upper and lower benches. Root development was accordingly deeper. In holes 1 and 2, root penetration to at least 30 inches is visible. In hole #5, near

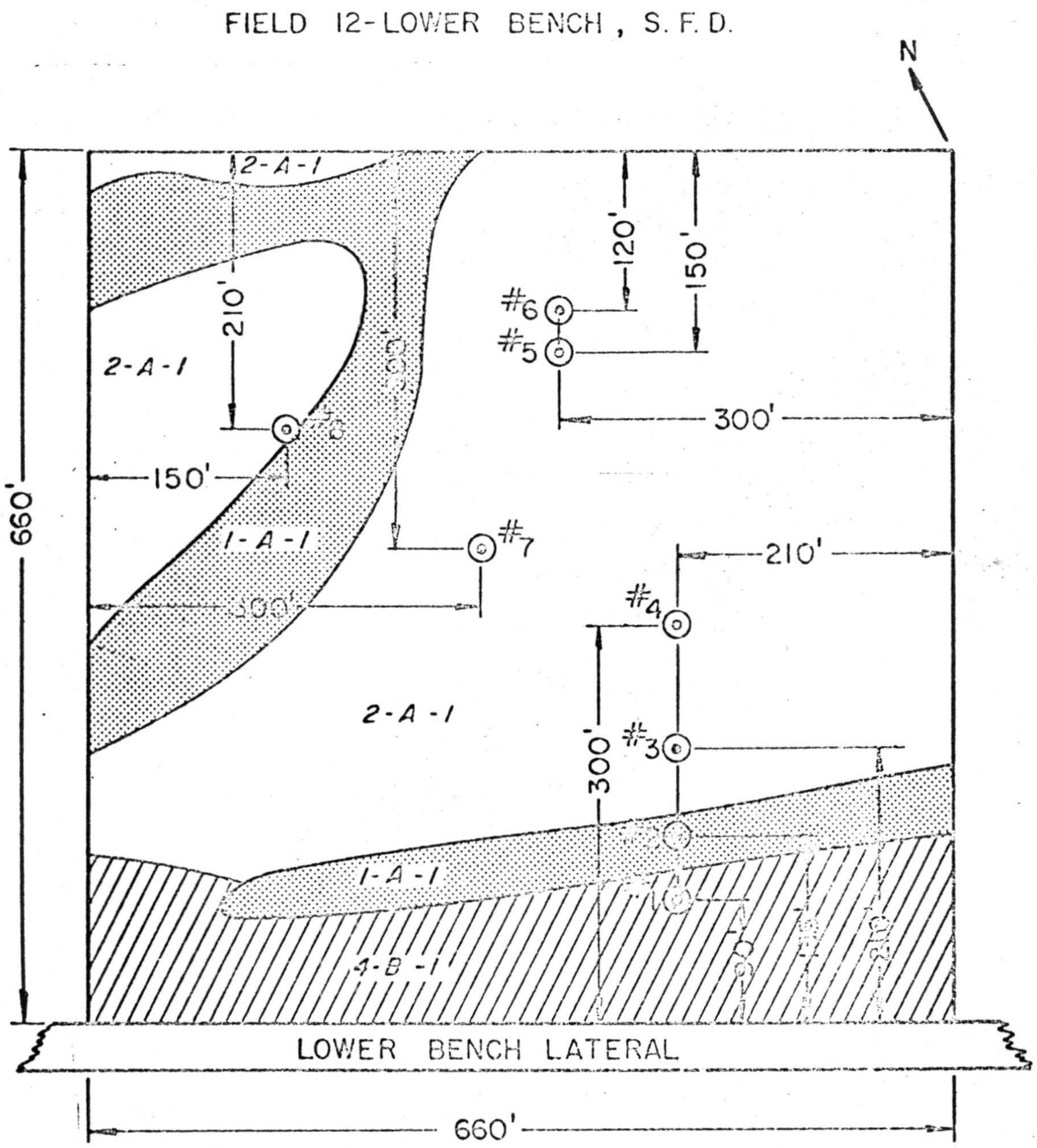
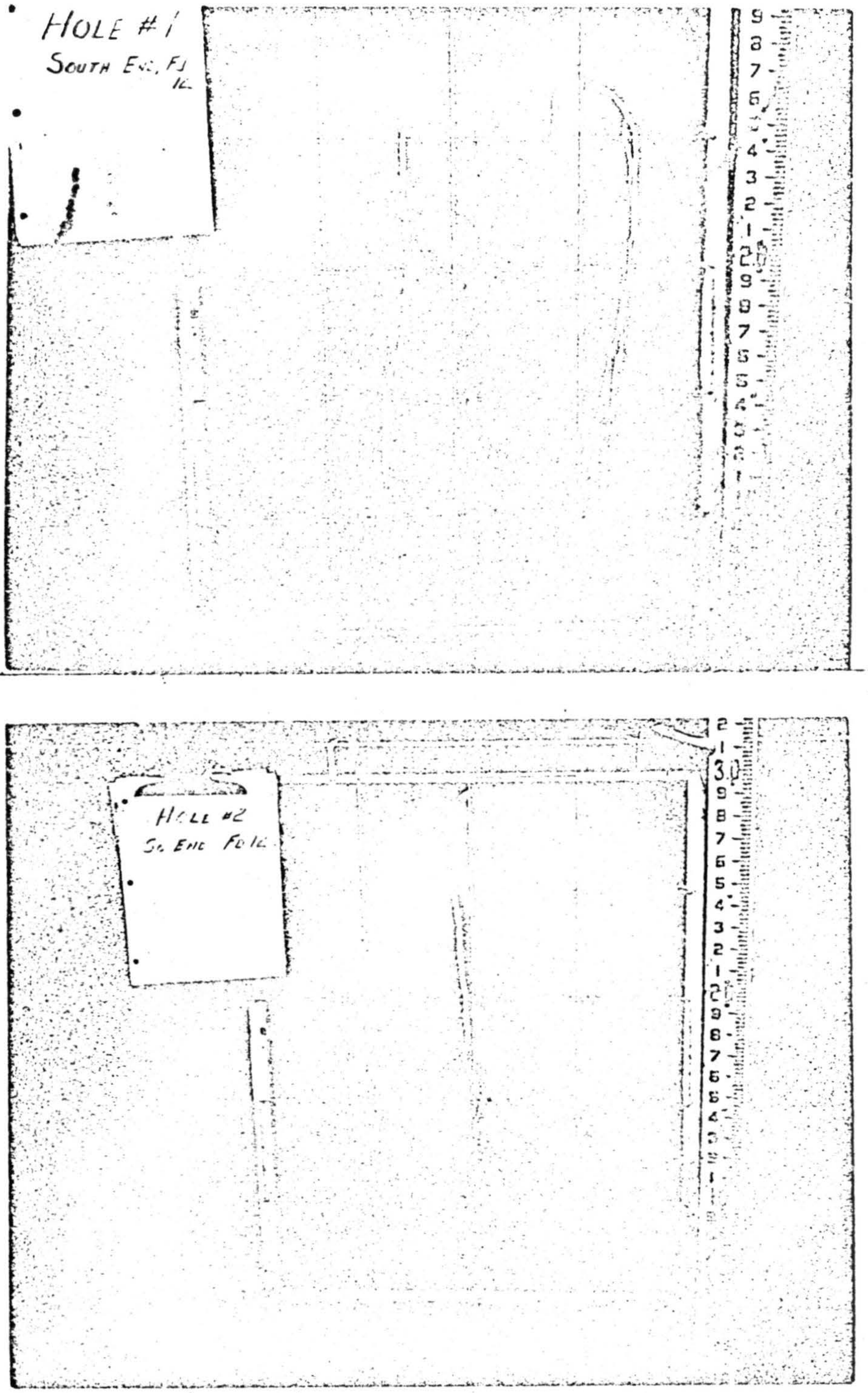
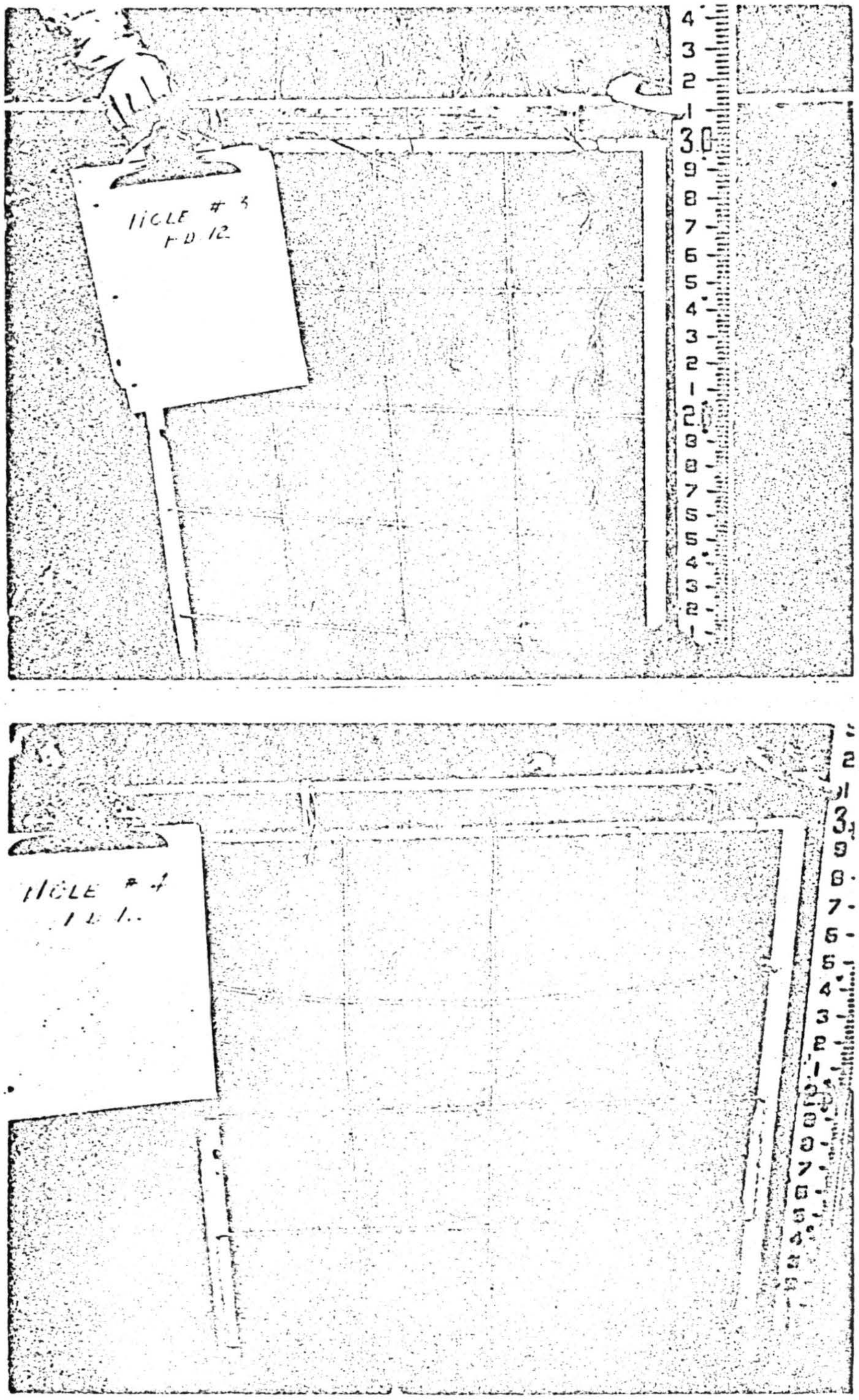


Fig. 4.--Location of root observation pits and distribution of soil types. Field 12, Seedskadee Development Farm. Soil Unit 4-B-1 consists of outwash from a scarp bordering Field 12. The soil is deep with adequate water holding capacity. Unit 2-A-1 soils are very shallow (5-20 inches) and underlain with coarse sand and gravel. Unit 1-A-1 soils are slightly deeper, but still require frequent irrigation.



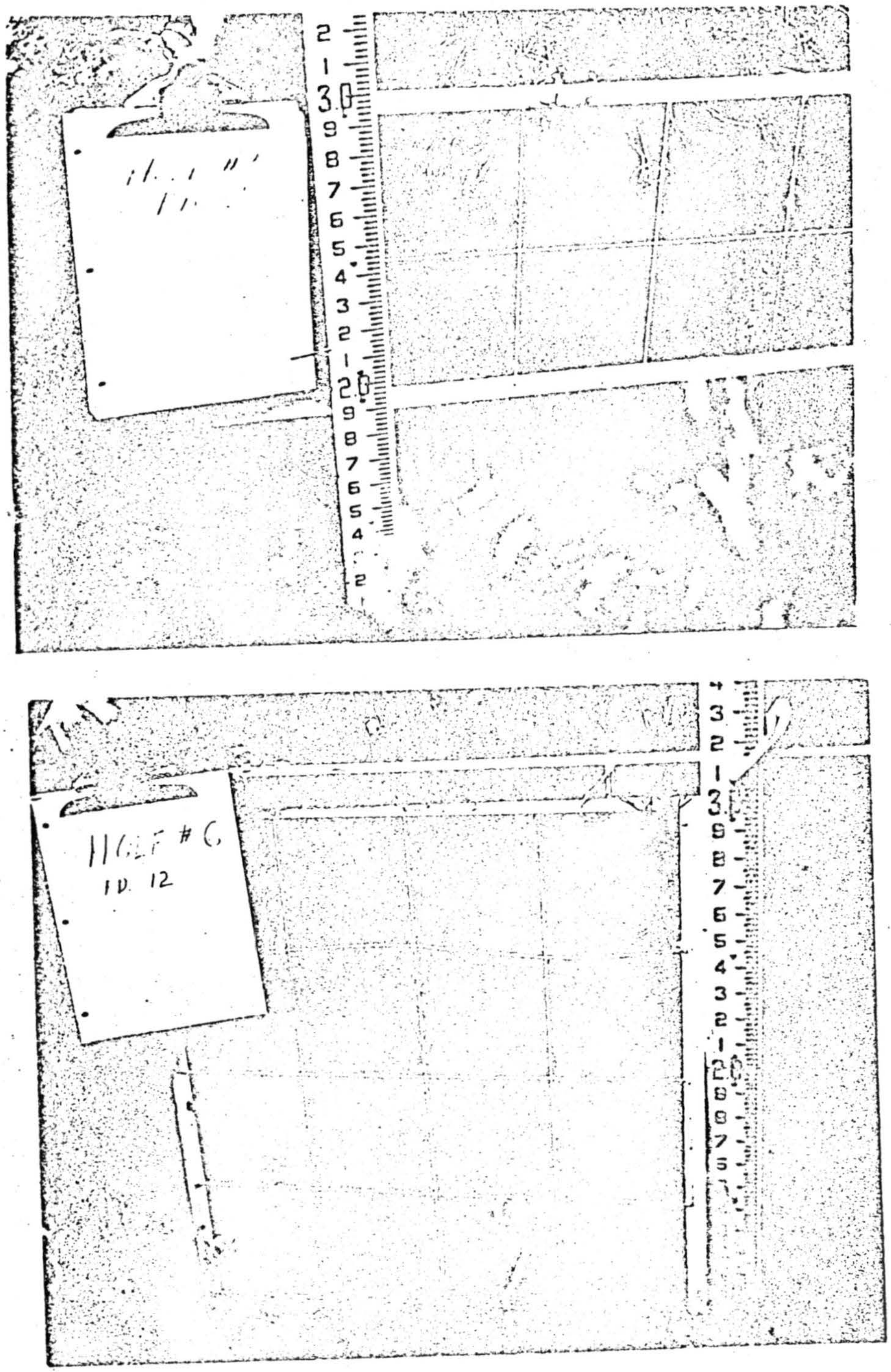
Figs. 5-6.--Root and soil profiles on Field 12, lower bench, Seedskadee Development Farm.

	Hole #1	Hole #2
Topsoil	24"	10-12"
Alfalfa Root Depth	36"	30"
Grass Root Depth	24"	24"



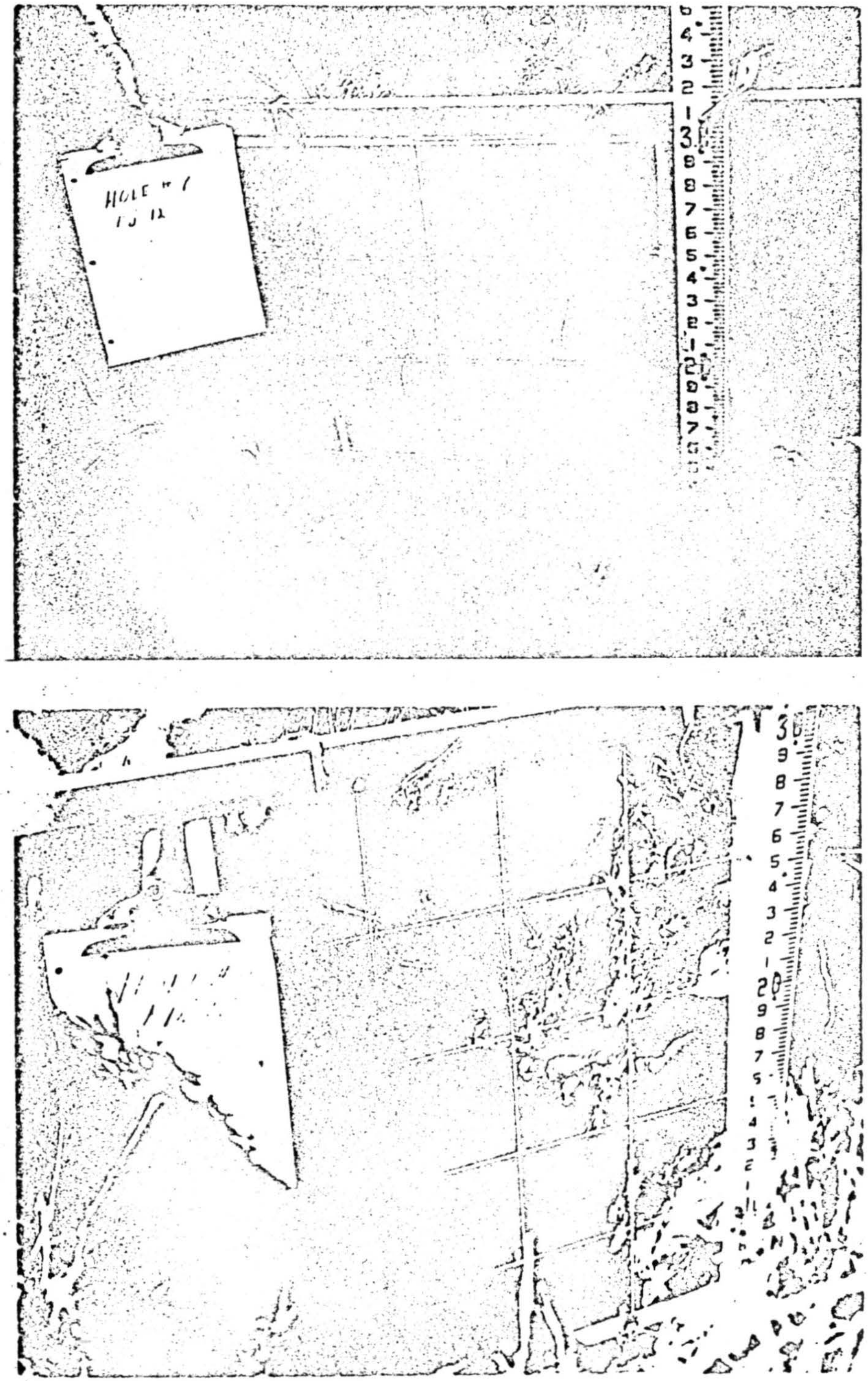
Figs. 7-8.--Root and soil profiles on Field 12, lower bench, Seedskadee Development Farm.

	Hole #3	Hole #4
Depth of Top Soil	6-8"	6"
Alfalfa Root Depth	30"	30"
Grass Root Depth	30"	30"



Figs. 9-10.--Root and soil profiles on Field 12, lower bench, Seedskadee Development Farm.

	Hole #5
Depth of Top Soil	12" (over sand)
Alfalfa Root Depth	8-12"
Grass Root Depth	8-12"



Figs. 11-12.--Root and soil profiles on Field 12, lower bench, Seedskadee Development Farm.

	Hole #7	Hole #8
Depth of top soil	8"	9" (cemented layer at 12-24")
Alfalfa root depth	30"	18"
Grass root depth	24"	12"

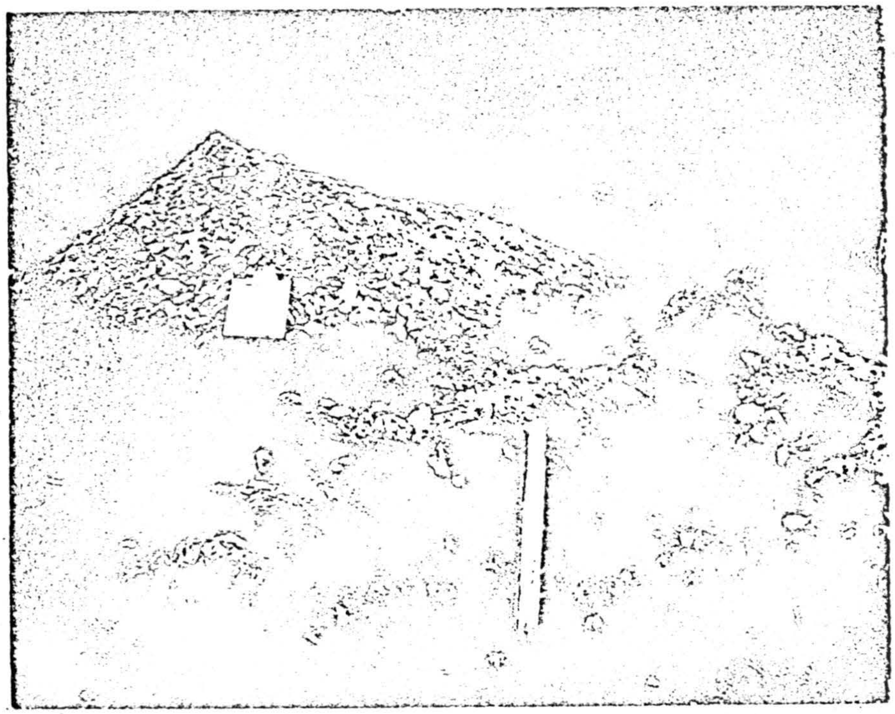


Fig. 13.--Typical crop growth and material removed from profile observation pits, Field 12, Seedskadee Development Farm.

the north end of the field, roots only penetrated about 12 inches. Restricted root growth, apparently due to a calcium layer, was noted in hole #8. Field 12 was seeded to grass and alfalfa in 1965. The roots shown in the photographs therefore represent approximately two and one-half seasons of growth under sprinkler irrigated conditions.

Field 13, Contour Dike System

Field number 13 was divided into strips by contour dikes at 0.5 foot vertical intervals. The dikes were 12 inches high with 3 to 1 side slopes. The leveling of hummocks to permit uniform distribution of water between dikes was made with a motor patrol. The contour dikes on this field were designed with a vertical interval such that, when water was backed up behind one of the dikes it would completely submerge the contoured area immediately above it, while still maintaining sufficient freeboard to prevent overtopping. Each dike was equipped with two to four gates. When the gates opened, runoff from surface storage in the uphill areas plus water supplied to the field through two turnouts would rapidly inundate the next area downhill.

Automation: The gates were of the semiautomatic, clock-operated, drop-open type, with butyl sheet or galvanized steel closures developed at the Snake River Conservation Research Laboratory (Fig. 14). The spring-wound timer on each gate was started by a float that released the clock mechanism when water reached the gate.

The contour dike system on field 13 allowed fair (about 90%) water coverage of the upslope benches and very poor coverage of lower benches, Fig. 15. An estimated 63 percent (9.8 acres) of the area of this field was covered by the 1966 irrigations. During this season, a total of about

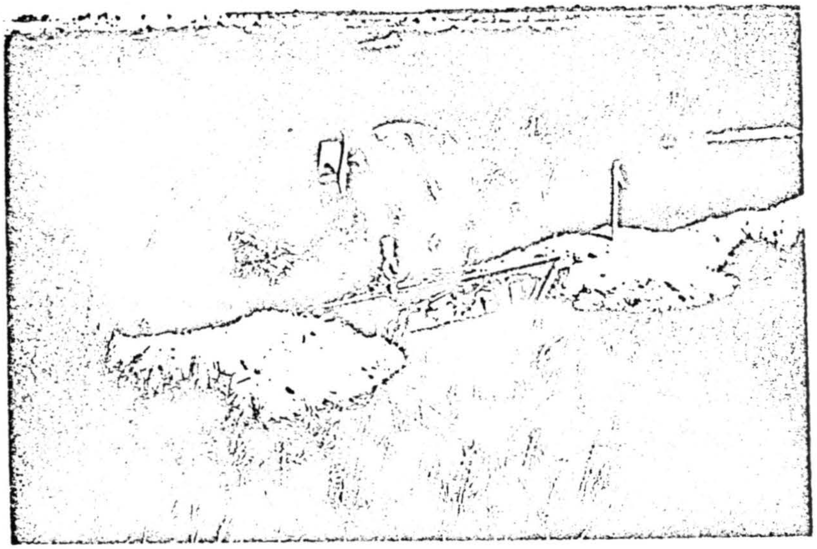


Fig. 14.--Semiautomatic check gate for releasing water from irrigated bench on field 13, Seedskadee Development Farm. The gate is released by a spring-wound timer. Elapsed time between water reaching the gate and gate opening can be preset as desired.

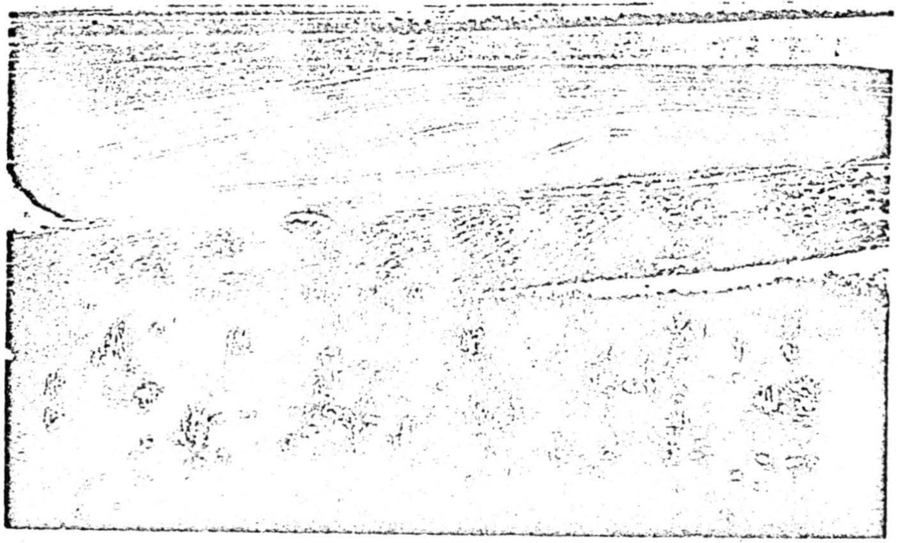


Fig. 15.--Field 13 on lower bench several hours after beginning of an irrigation. Note uneven water coverage and crop growth.

15 inches of water was applied to this irrigated area in six irrigations. During the latter part of the season, seepage from the lower bench lateral and drains produced a water table around the south and east edges of field 13 high enough to contribute to crop water needs. There was no runoff of water from this field.

Fifty-three bales of hay were harvested from field 13 at the first cutting. This represents about 4 tons from the 9.8 acre irrigated portion of the field. At the time of the second cutting, 117 bales were harvested. Much of the increase is attributed to subirrigation effects immediately downslope from the lower bench lateral.

Gravimetric soil samples were taken before and after the July 12, 1966 irrigation on field 13. The maximum sampling depth was 12 inches in this rocky soil. Results from 16 locations, representing the 9.8 wetted acres on this field, indicate that 0.82 inches of water was added to the top foot of soil by the irrigation. This moisture, plus the evapotranspiration correction for the period between samplings, accounts for 50 percent of the water applied. Since additional water was no doubt stored in the second foot of the profile, a reasonably good water application efficiency is indicated. It was obtained, however, as a result of only partial coverage of the field. Water losses were primarily due to deep percolation in the upper one or two benches, where water remained on the surface for several hours. Five applications of water were made on field 13 during 1967. Three carefully measured applications averaged 2.65 acre feet. The total application for the season is estimated at 13.30 acre-feet. Field 13 has an area of 15.6 acres. The irrigation coverage was estimated to be 60 percent of the total area or about 9.4 acres. The average depth of water applied to the irrigated area was, therefore, about 17 inches. There was no runoff from field 13.

Much of the additional area ofthis field received water from a high water table that developed as a result of seepage from the lower bench lateral. Thus yields on field 13 were maintained in spite of the infrequent irrigations.

The semiautomatic gates on this field performed with limited effectiveness. Problems were:

1. Friction in the gate mechanism, coupled with low depths of water, so that gates would not drop open after the clocks had released.

2. Clocks not starting, because the starting float rod was not free to rise. More guides for the float rod would have solved this problem.

3. Poor synchronization of gates in a single dike, because the slow advance of water could cause the clock on one gate to start at a considerably different time than clocks on other gates. Overall, the gates were judged to be about 70 percent effective.

During 1967, the water table under field 13 had risen to a level, due to seepage from the lower bench lateral, such that only very infrequent irrigations were needed over most of the field area.

Research Area - Upper Bench

The upper bench research area consists of 23 acres, immediately adjacent to the main 300 acre block of the development farm. The area was developed in order that the hydraulics and efficiencies of border irrigation on Seedskadee soils could be studied and various methods of automating water releases to these borders could be evaluated. The need for study and objectives were described as follows in the ARS research outline:

Need for Study:

The Seedskadee Development Farm was established to determine the economic feasibility of completing an irrigation development in western Wyoming. If completed, 60,000 acres of arid land will be provided with water for production of pasture crops, hay and small grains. Success of the development will hinge, in part, on an efficient irrigation system design, capable of applying water with minimum loss and minimum labor.

The research area on the Seedskadee Development Farm, where this study is to be conducted, provides an opportunity to evaluate effects on efficiency of varying discharge, length of run and application time on Seedskadee project soils. Research on the development farm will also provide information on minimizing labor requirements and land preparation expense.

Objectives:

1. To develop devices and new systems of irrigation to conserve irrigation water supplies by utilizing automatic control of water to reduce labor requirements.

2. To develop systems to apply irrigation water to irrigated fields, at the optimum rate of discharge and for the optimum length of time, automatically, utilizing existing pipeline valves or open ditch turnouts.

3. To automate the release of water on a project basis by controlling the rate of flow through farm headgates.

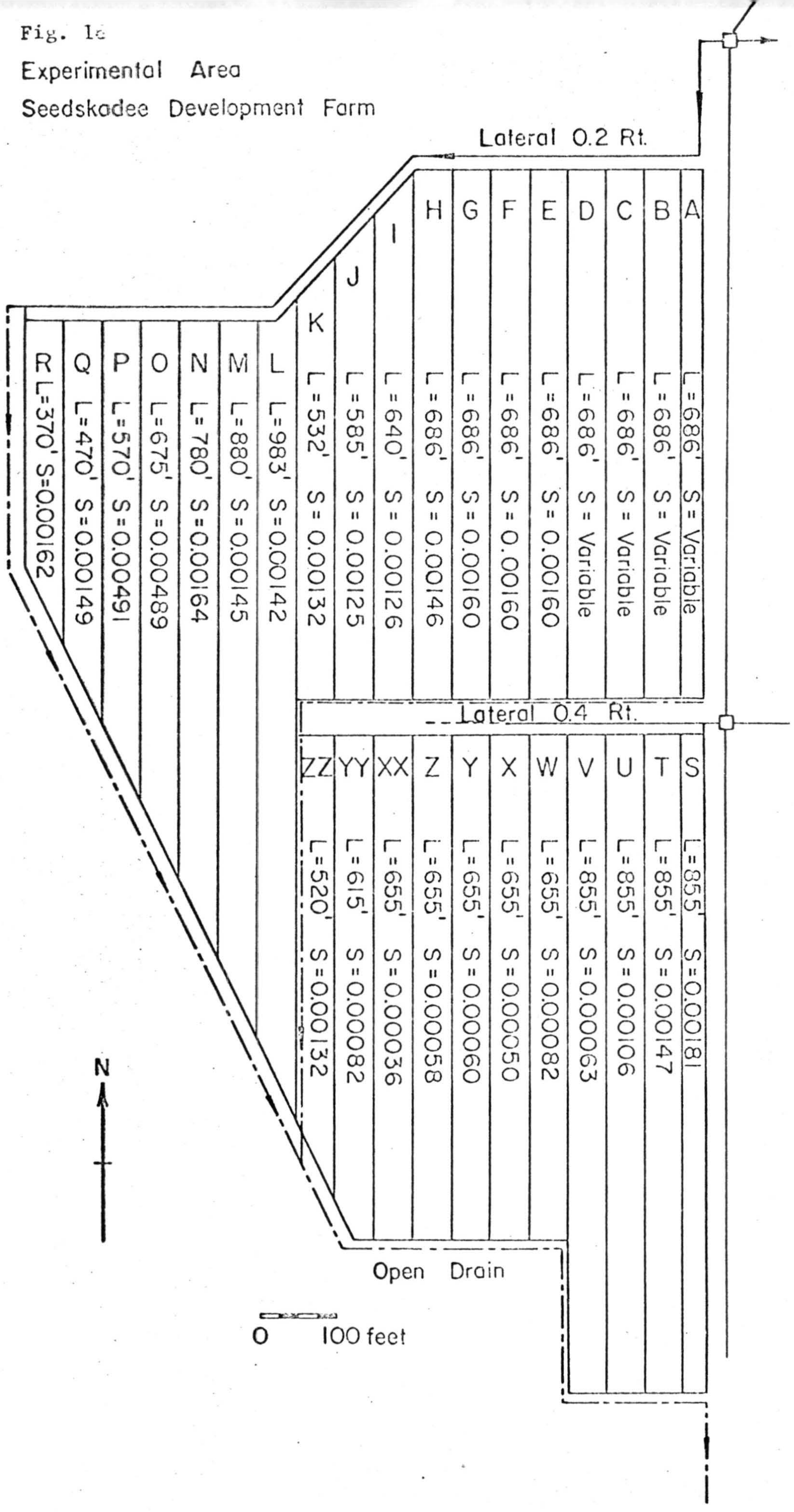
4. To develop safety devices that will prevent damage to land or structures if automatic valves malfunction.

5. To develop checks in open field laterals that can be opened or closed automatically.

6. To further develop electronic components for reliable operation of automatic irrigation systems.

Land Preparation: The upper bench research area was cleared in 1965. Twenty-six borders of varying lengths were constructed, served by two irrigation laterals (Fig. 16). After land grading, the 26 experimental borders had slopes ranging from 1/10 to 2/10 of one percent and lengths varying from 340 to 1350 feet.

Fig. 1c
Experimental Area
Seedskadee Development Farm



After one trial irrigation in 1965, it was decided that three of the borders were too long for effective irrigation. Also, the quality of land forming on the entire research area was not adequate to provide uniform spreading of the irrigation stream over the borders. Therefore, a new contractor was hired later in the summer of 1965 to refine the land forming and to bisect the three long borders by lengthening lateral 0.4 Rt (Fig. 16) 150 feet and relocating the drain ditch.

Four of the borders, A through D, had cross-slope only removed. However, in checking border topography one year after land forming, longitudinal slope variations on other borders were found to vary as much as on these four. Border dikes on all upper bench borders were built in accordance with specifications for the rest of the development farm.

Water supply to the borders was through 15-inch pipe turnouts, having sloping concrete collars and hand-operated, galvanized steel slide gates on the upstream ends.

Automation: A system incorporating lay-flat pneumatic valves in the 15-inch pipe turnouts to automate irrigation of this field was installed in 1965, Fig. 17. Air pressure to activate the valves was transmitted to the turnout locations through 3/4 inch polyethylene tubing. Pneumatic valves at three or four turnouts were connected to a single air control box, Fig. 18, so that these turnouts could be opened by a single signal from the transmitter.

The pneumatic valve automation worked reasonably well during 1966. Problems were caused by small holes which developed in the reinforced butyl rubber, probably ozone cracking. The resulting air leakage allowed some water seepage through the turnouts and kept the compressor running

Fig. 17--. Lay-flat pneumatic valve for 15-inch pipe turnout. Valve is normally fixed within pipe behind existing slide gate.

Fig. 18.-- Tone-telemetry receiver and 3-way air control valve used to control irrigation water releases with lay-flat pneumatic valve.

more than should have been necessary. The most distant control point was about 1000 feet from the transmitter. Voltage losses at such distances were not extreme for the cable used and the tone-telemetry signalling system worked satisfactorily. However, for longer distances, high and possibly hazardous voltages would be required to transmit power to the solenoid valves at the receiver locations. For these reasons, the pneumatic automation system was replaced with a hydraulic system late during the summer of 1966.

The hydraulic system utilized butterfly gates on each turnout, activated by brass hydraulic cylinders, Fig. 19. The brass cylinders were mounted on the ditch bank, above the gates so that they were above the water surface at all times. A domestic water system, Fig. 20, furnished pressure to the cylinders (using filtered ditch water) at 60 to 70 psi.

The cylinders were controlled by three-way valves in float wells located to sense advance of water on the borders. The first set of gates was opened when water reached a well located inside the ditch bank near the first check structure. The logic of the system is very similar to one installed on a citrus orchard in Yuma, Arizona.[1/] (Fig. 21).

Two semiautomatic checks were installed in modular steel structures in the long lateral, Fig. 22. The checks, constructed of butyl rubber sheeting, were tripped by a hydraulic cylinder, then reset manually.

Only minor problems occurred in operating this system in the fall of 1966 and 1967 seasons. Rodent damage to the small polyethylene control lines caused some malfunctions. Two of the 19 brass cylinders were

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[1/] Haise, Kruse and Erie. Automating Surface Irrigation. Agr. Engr., Vol. 50, No. 4, pp. 212-216, April 1969.

Fig. 19.--Butterfly turnout gate, powered by brass hydraulic cylinder. The brass cylinders are operated with water pressures of 50 to 80 psi controlled by float valves that sense water advance on the irrigated borders.

Fig. 20.--Equipment for providing water pressure for hydraulic automation system. Pump takes its supply from open irrigation ditch. All water passes through filter (behind pressure tank) before entering field supply line.

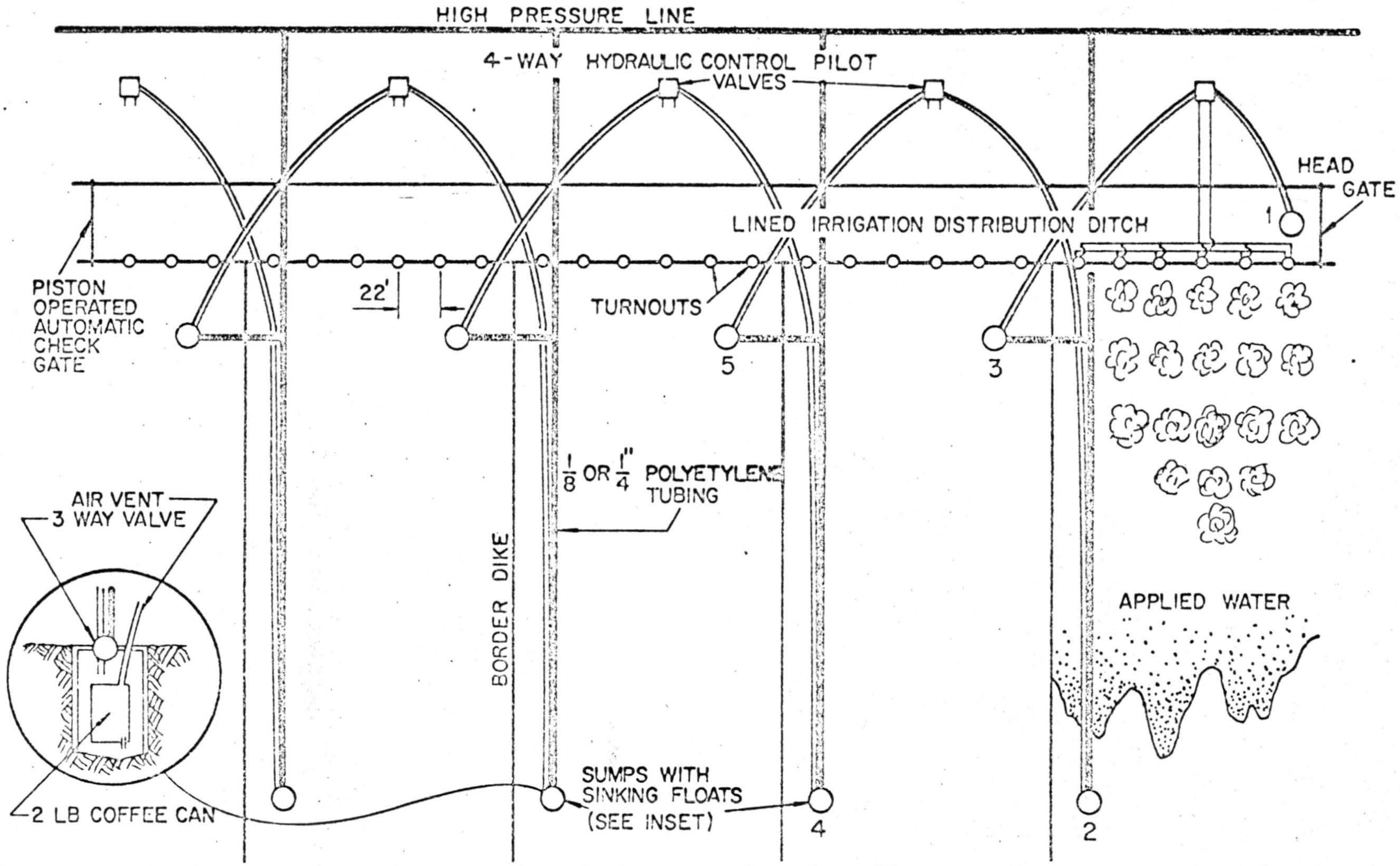

Figure 21.--Schematic diagram of automatic surface irrigation adapted to 10 acres of citrus grown on the Yuma Mesa, Ar Sequence of operation is as follows: (A) Headgate is opened, (B) Water fills cement lined irrigation distribution dit and overflows stilling well #1 which hydraulically activates 4-way pilot valve (far upper right) opening first set of six turnout gates, (C) Water flows between border dikes of first irrigation set to stilling well #2. Inflow of water here causes 3-way valve to open actuating second 4-way pilot valve (2nd from right) causing second set of six turnout gates to open, (D) Water flowing through turnouts enters stilling well #3 actuating the first 4-way pilot valve that closes the first set of six gates, and (E) Water flows between border dikes to stilling well #4 which actuates the 4-way pilot valve (3rd from right) opening the third set of six turnout gates. Sequence is repeated until entire bloc is irrigated and automatic check gate (far upper left) releases water to the next 10-acre block to be irrigated. (See Figure 10)

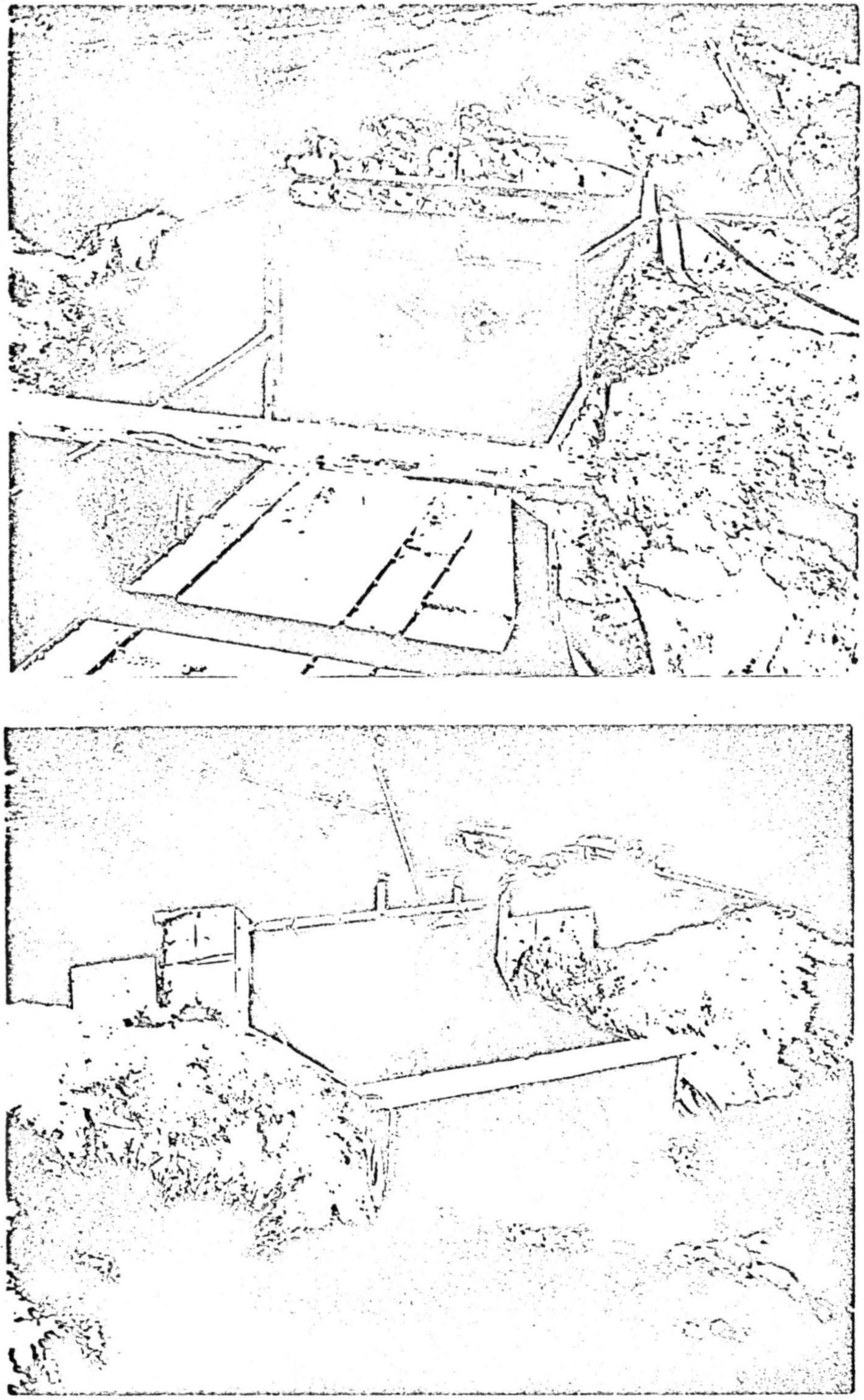

Fig. 22.--Semiautomatic hydraulically opened check installed in automated lateral on Seedskadee Development Farm. Checks are opened by hydraulic cylinders tied to same controls described in Figure 19.

damaged by freezing when the system was not drained early enough in the fall of 1966. Plastic hydraulic cylinders have now been developed that are corrosion resistant. Alcohol can be used to winterize system.

Proper location of the downstream float wells is accomplished by trial and error. It was necessary to move some wells once or twice after their first placement to get irrigation applications of the proper duration. The upstream control wells were sometimes located too near low spots on the border dike of a set being irrigated. Water spilling over the dike adjacent to the nonwatered area sometimes would cause the open gates to close prematurely. The problem could have been eliminated by locating the upstream wells in one of the center borders of an irrigation set.

The rubber-gasketed butterfly gates built for this system worked well, allowing less leakage than the steel slide gates originally installed on the turnouts. Careful adjustment of the gates was necessary to prevent them from sticking after several days in the closed position. Again this problem could have been resolved by use of larger plastic cylinders operating at higher prssures than used with the Seedskadee system.

Irrigation Efficiencies and Hydraulics

A Troxler neutron depth moisture gage was used in an attempt to determine changes in soil moisture before and after irrigations. The gage was calibrated in three different ways (all comparisons with gravimetrically obtained samples), Fig. 23. All calibrations differed and, furthermore, none agreed with the standard calibration furnished by the manufacturer. Therefore, results of all soil-water determinations are questionable and are not used extensively in this report.

Fig. 23.--Calibration of neutron depth moisture gage in area of deep soil near research area. Large (2000 cc) samples were taken in this area to gravimetrically measure water content and bulk density.

The rocky, shallow nature of the soils at Seedskadee made it impractical to take adequate gravimetric samples to define irrigation efficiencies and consumptive use rates.

Evapotranspiration: Spot checks of ET values were estimated using the Jensen-Haise equation:[1]

$$\frac{ET}{R_S} = 0.014T - 0.37 \tag{1}$$

where:

ET is the potential evapotranspiration

R_S is the total solar radiation in units of equivalent depth of water evaporated and T is mean daily temperature.

A modified Penman-type equation was also used:

$$ET = \frac{\delta}{\delta+\gamma}(R_n) + \frac{\delta}{\delta+\gamma}(15.36)(1.0 + .01W)(e_s - e_d) \tag{2}$$

where: δ is the slope of the saturation vapor pressure-temperature curve

γ is the psychometric constant

R_n is net radiation

W is total daily wind run

e_{-}^{s} are saturation vapor pressures.

Climatological data for use in the equations were measured on the Development Farm, (Fig. 24) and are summarized in Appendix A. Values obtained from equations 1 and 2 are shown for comparison in Table 1.

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[1] Jensen, M. E. & H. R. Haise. Estimating Evapotranspiration from Solar Radiation. Journ. of I&D Div., ASCE. December 1963.

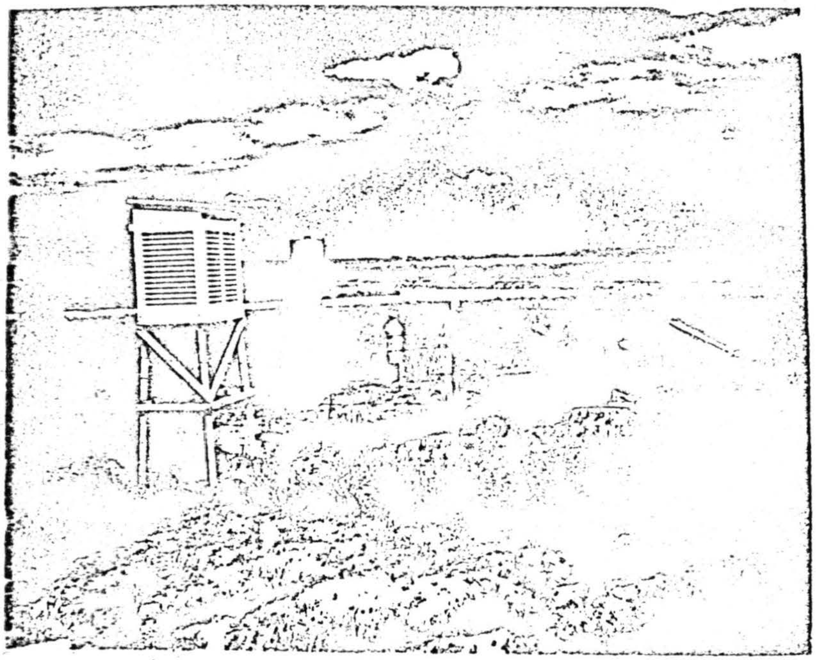

Fig. 24.--Seedskadee Development Farm Weather Station **including:** recording evaporation pan, standard and recording rain gages, anemometer, and hygrothermograph. A pyranometer for recording total solar radiation was also available in 1966 and 1967.

There is reasonably good agreement between the two estimates during the mid-season. Early in June, when high winds are common in the Seedskadee area, the Penman-type equation gives significantly higher estimates of ET than the Jensen-Haise.

TABLE 1. Selected Daily Values of Potention Evapotranspiration as Estimated by Two Different Methods

	Estimated Evapotranspiration		
Date	Modified Penman Inches	Jensen-Haise Inches	Difference Percent
6-5-67	.18	.12	50
6-13-67	.22	.17	29
6-19-67	.29	.30	-3
6-27-67	.32	.31	3
6-30-67	.32	.34	-6
8-16-67	.23	.27	-15
8-23-67	.21	.20	5
8-29-67	.27	.24	8
8-30-67	.13	.07	86

The soil moisture changes between irrigations offer one means of estimating evapotranspiration for the crop on the research area. Daily measurements of total solar radiation and temperature during the summer months present a second basis for ET estimation.

Table 2 presents comparative ET and evaporation values determined for periods of several days and for the growing season in 1967. Columns 3 and 4 contain estimates of ET as computed by USBR personnel, based on equation 1 but using different crop coefficients. The use rates determined from soil moisture samples corresponded reasonably well with solar radiation during the early and late portions of the growing season.

During July and the first two weeks of August, soil samples indicated lower rates of ET than were estimated from radiation. ET lower than potential may have occurred because of lack of available water in the crop root zone during this period; especially from 7/2 to 7/17 when there was a 17-day interval between irrigations caused by a delay in hay harvesting.

Values of ET in columns 2, 3 and 4 of Table 2 are estimated from solar radiation and other climatic variables. (Measured values of solar radiation and other climatic variables for the growing seasons 1965-67 are contained in Appendix A.) Differences in the three columns are less than 6 percent over the total growing season. Larger variations occur over short sampling periods. The reasons for the difference are that different crop characteristic curves have been assumed for the different methods. That is, the reduction from estimated potential ET

TABLE 2

Short-Term ET on Seedskadee Farm near Fontanelle, Wyoming in 1967, measured and/or computed.

Period 1967	1 Soil Water Samples inches	2 J-H inches	3 Alfalfa inches	4 Wheat Grass inches	5 Class A Evap. inches
6-16 / 6-28	2.55	2.80	2.79	2.53	2.12
7-2 / 7-17	2.25	3.05	3.61	3.39	-
7-20 / 7-30	1.75	2.82	2.49	2.08	3.24
8-4 / 8-14	2.26	2.89	3.08	2.83	2.90
8-19 / 8-29	2.22	2.24	1.68	1.91	3.63
Growing Season					
5-16-67 / 9-15-67		23.3	22.8"	22.1	
6-1 / 9-15		22.2			29.47

occurring at the beginning and end of the season, after frosts and after hay cutting were based on different assumptions. No one estimate compares consistently better than the others with the ET estimated from soil moisture samples for the short periods.

Over the 1967 growing season, ET estimated from solar radiation was 23.3 inches or 76 percent of the evaporation from a Class A pan. In 1966, the June 15-September 9 ET estimated from radiation totaled only 13.44 inches. Pan evaporation for the same period was 30.46 inches. Based upon comparisons from other sources, ET is often about 0.8 of evaporation from a Class A pan.

The seasonal ET estimates of 22 to 23 inches, based on solar radiation and air temperature measurements, compare closely with gross applications of water by the center pivot sprinkler on a field of oats in 1967. Gross application to the oats field was 16.6 inches plus an additional 3.2 inches of rain.[1/] The field was not watered for a 20-day period between August 28 and September 17 while oats was being harvested. Thus, assuming high application efficiencies for the center pivot sprinkler and similar soil water content at the beginning and end of the season, water applied and used consumptively would not differ greatly from estimated ET.

Water Holding Capacity Determinations: Laboratory determinations of field capacity, wilting point and available water from upper bench field samples are shown in Table 3.

[1/] Barnes (see earlier citation).

TABLE 3

Moisture Characteristics of Upper Bench Soils, Seedskadee Development Farm, Fontanelle, Wyo.

Source	Sample Location	Depth Samples	FC* (1/3 Bar)	WP (15 Bar)	ASW Inches	Est. ASW in 42" depth
USBR	Fds 1-9	18-46" (ave-31")	-		2.72	3.89
USBR	" (before leveling)	36" & 48"	3.1		2.94	2.94
ARS	Res. Area	24"	4.15	2.15	2.00	3.50

*values may be low if field capacity is actually nearest to 0.1 bar.

The value for available soil water in the 42-inch depth of 3.50 inches seems reasonable when compared with USBR analyses. Extrapolating field capacity and wilting point determinations, the respective values for a 42-inch soil depth would be 7.3 and 3.8 inches.

Most of the soils on the development farm are shallow underlain with sands and gravels at depths of 1 to 3 feet. Resistance to deep drainage of soil water caused by the soil-gravel interface could account for greater soil water storage than indicated by laboratory estimates of field capacity.

<u>Soil Water Balance Through 1967</u>: A record of soil water conditions on selected borders of the upper bench research area is given in Table 4. The soil water contents were determined with the neutron depth gauge, using the calibration obtained by comparison with large gravimetric samples obtained. All water measurements represent sampling depths of 42 inches unless otherwise noted. There were four sampling locations on most borders. Differences between soil water content before and after irrigation, when corrected for

Table 4. Soil Water Budget - Upper Bench Research Area - Seedskadee Development Farm - 1967

	BORDER											
	4	5	10	13	17	19	20	21	22	25	26	29
Wilting Point[1]	3.83	3.83	3.83	2.19[2]	3.83	3.83	2.74[3]	3.83	3.83	3.30[4]	3.83	3.83
Field Capacity	7.20	7.20	7.20	4.10[2]	7.20	7.20	5.15[3]	7.20	7.20	6.20[4]	7.20	7.20
Avail. Soil Water	3.37	3.37	3.37	1.91[2]	3.37	3.37	2.41[3]	3.37	3.37	2.90[4]	3.37	3.37
Before Irr. 6/12	8.07	8.88	9.38	4.95[2]	7.33	7.35	5.65[3]	8.06	8.78	6.28[4]	7.59	7.01
After Irr. 6/16	9.55	9.86	10.65	5.76	8.38	9.24	7.00	9.85	10.33	7.60	8.82	8.48
ET 6/12-6/16	0.70	.70	.70		.70	.70	.70	.70	.70	.70	.70	.70
Precip. 6/12-6/16	0.51	.51	.51		.51	.51	.51	.51	.51	.51	.51	.51
Soil Water Added	1.67	1.17	1.46		1.24	2.08	1.54	1.98	1.74	1.51	1.42	1.66
Before Irr. 6/28	8.35	9.05	9.47	4.68	7.11	7.19	5.46	7.82	7.64	5.37[3]	7.51	5.51[3]
Precip. 6/16-6/28	0.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98
Soil Water Used	2.18	1.79	2.16		2.25	3.03	2.52	3.01	3.67		2.29	
Daily ET (Meas)	.18	.15	.18		.19	.25	.21	.25	.31		.19	
Daily ET (Est)[5]	.23											
After Irr. 7/1			10.34	6.47	7.69	8.12	6.20	9.24	10.10	6.20	8.17	6.31
After Irr. 7/3	8.31	9.21										
ET	1.56	1.56	0.93	.93	.93	.93	.93	.93	.93	.93	.93	.93
Soil Water Added	1.52	1.89	1.80		1.51	1.86	1.67	2.35	3.39	1.76	1.59	1.73

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[1] Soil water given as inches water in 42-inch root zone unless otherwise noted.
[2] 24-inch sample depth.
[3] 30-inch sample depth.
[4] 36-inch sample depth.
[5] Estimated from Jensen-Haise Formula.

Table 4 (cont.)

	4	5	10	13	17	19	20	21	22	25	26	29
Before Irr. 7/17	8.41	7.71	7.61	3.61	5.68	7.11	4.61	6.81	8.00	4.67	5.51[4/]	4.14
Precip.	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40	.40
Soil Water Used	.30	1.90	3.13	3.26	2.41	1.41	1.99	2.83	2.50	1.93	3.06	2.57
ET (Meas)	.02	.14	.20		.15	.09	.12	.18	.16	.12	.19	.16
ET (Est)	.19	.19	.21		.21	.21	.21	.21	.21	.21	.21	.21
After Irr. 7/20	8.70	8.88	9.10	5.20	7.95	7.70	5.92	9.66	8.15[4/]	5.44	6.92	6.19
ET (Est)	.65											
Precip.	.05											
Soil Water Added	0.89	1.77	2.09		2.87	1.19	1.91	3.45	2.23	1.37	2.01	2.65
Before Irr. 7/30	6.86	6.06	6.80	3.50	5.56	6.22	4.93	8.15	7.05	3.81	5.46	5.66
Precip.	.00											
Soil Water Used	1.84	2.82	2.30	1.70	2.39	1.48	.99	1.51	1.10	1.63	1.46	0.53
Daily ET (Meas)	.18	.28	.23	.17	.24	.15	.10	.15	.11	.16	.15	.05
Daily ET (Est)	.28											
After Irr. 8/3						7.83	6.27	9.55	8.47	5.04		6.68
After Irr. 8/4	7.94	8.18	8.55	5.01	7.30						6.85	
ET (Est)	1.53	1.53	1.53	1.53	1.53	1.25	1.25	1.25	1.25	1.25	1.53	1.25
Precip.	.05	.05	.05	.05	.05	.00	.00	.00	.00	.00	.05	.00
Soil Water Added	2.56	3.60	3.23		3.22	2.86	2.59	2.65	2.67	2.48	2.92	2.27
Before Irr. 8/14	5.25	5.57	5.69	3.16	5.24	6.04	4.39	6.94	6.16	3.06	4.72	3.52
Precip.	.00											
Soil Water Used	2.69	2.61	2.86	1.85	2.06	1.79	1.88	2.61	2.31	1.98	2.13	3.16
ET (Meas)	.27	.26	.29	.19	.21	.18	.19	.26	.23	.20	.21	.32
ET (Est)	0.29											

Table 4 (cont)

	4	5	10	13	17	19	20	21	22	25	26	29
After Irr. 8/18					7.12	7.23	5.76	9.20	9.79[6/]	5.70	7.25	5.88
After Irr. 8/19	8.08	7.36	7.41	5.35								
Precip.	.05	.05	.05	.05	.03	.03	.03	.03	.03	.03	.03	.03
ET (Est)	.99	.99	.99	.99	.78	.78	.78	.78	.78	.78	.78	.78
Soil Water Added	3.77	2.73	2.66		2.63	1.94	2.12	3.01	3.04	3.39	3.26	3.11
Before Irr. 8/29	5.26	4.89	4.97	3.36	4.94	5.51	3.96	6.05	7.37	3.61	4.68	3.42
Precip.	.00											
Soil Water Used	2.82	2.47	2.44		2.18	1.72	1.80	3.15	2.42	2.09	2.55	2.46
ET (Meas)	.28	.25	.24		.20	.16	.16	.29	.22	.19	.23	.22
ET (Est)	0.22											
After Irr 9/1						7.73	5.94	8.68	9.64	6.05	6.86	
After Irr 9/2	7.62	6.91	8.20	5.08	6.57							
Precip.	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03	.03	
ET (Est)	.59	.59	.59	.59	.59	.43	.43	.43	.43	.43	.43	
Soil Water Added	2.92	2.58	3.69		2.19	2.62	2.38	3.03	2.67	2.84	2.58	

6/ 42-inch sample depth.

estimated ET and measured precipitation, represent water stored in the 42-inch soil profile by the irrigation. These values of stored water are used to determine field irrigation application efficiency.

The change in soil water content between irrigations, corrected for precipitation, has been cited earlier as an estimate of ET.

It is possible that high water table may have affected soil moisture measurements on the research area during some parts of the irrigation season. If so, some of the low apparent ET rates could be explained. During the summer of 1966, for instance, the water table rose to within 2.6 feet of the ground surface in an observation well located in field 3, immediately adjacent to the research area. No free water was observed, however, in the 42-inch deep neutron access tubes in the research area during either 1966 or 1967.

The coefficient of uniformity of water application was computed for each border where neutron moisture readings were taken. Individual coefficients are based on only 4 sampling locations per border. These 4 locations were uniformly spaced along the length of the border. Where neutron readings could not be taken to a depth of 42 inches, the soil water content in the measured depth was extrapolated to 42 inches as an estimate of water retained in the profile. ET corrections are again from estimates based on measured solar radiation.

The average coefficient of uniformity for 6 irrigations of all borders was 78.9. The average of all borders for each irrigation remained nearly constant through the season with the exception of the July 18 irrigation, when the value was only 68.5. This irrigation was applied after the longest interval of any (18 days after the previous irrigation) during the 1967 season. No consistent variation of uniformity coefficient with length of border was observed.

Border Hydraulics Measurements: Detailed irrigation hydraulics measurements were made on three upper bench borders for each of three irrigations in 1967. Times of advance and recession were measured at stations 25, 50 and every 100 feet from the upstream end of the border. Depth of flow (referenced to benchmarks set at the average elevation of each station) was measured periodically during the irrigation. Four cylinder infiltrometers were used to obtain values of intake during each irrigation. Because of dry, rocky conditions prior to an irrigation, the infiltrometers could be driven only 1 or 2 inches into the soil. Buffering was accomplished by filling the infiltrometer at the time it was reached by the surface irrigation stream. Head differentials did exist between water in the infiltrometer and the surrounding flow.

The resulting measurements made it possible to estimate (1) rates of advance and recession, 2) volume of water in surface storage at any time and 3) depth of water infiltrated at any point on the border and total volume infiltrated at any time. These quantities, along with the regular measurements of inflow, application time and runoff, made it possible to obtain estimates of water application and distribution efficiencies, independent of soil water measurements.

The following set of figures (25-27) show an example of results of such measurements and analyses for one irrigation of Border Y that occurred on 8/30/67. A gross application of 2.94 inches was made to this 47.5 feet

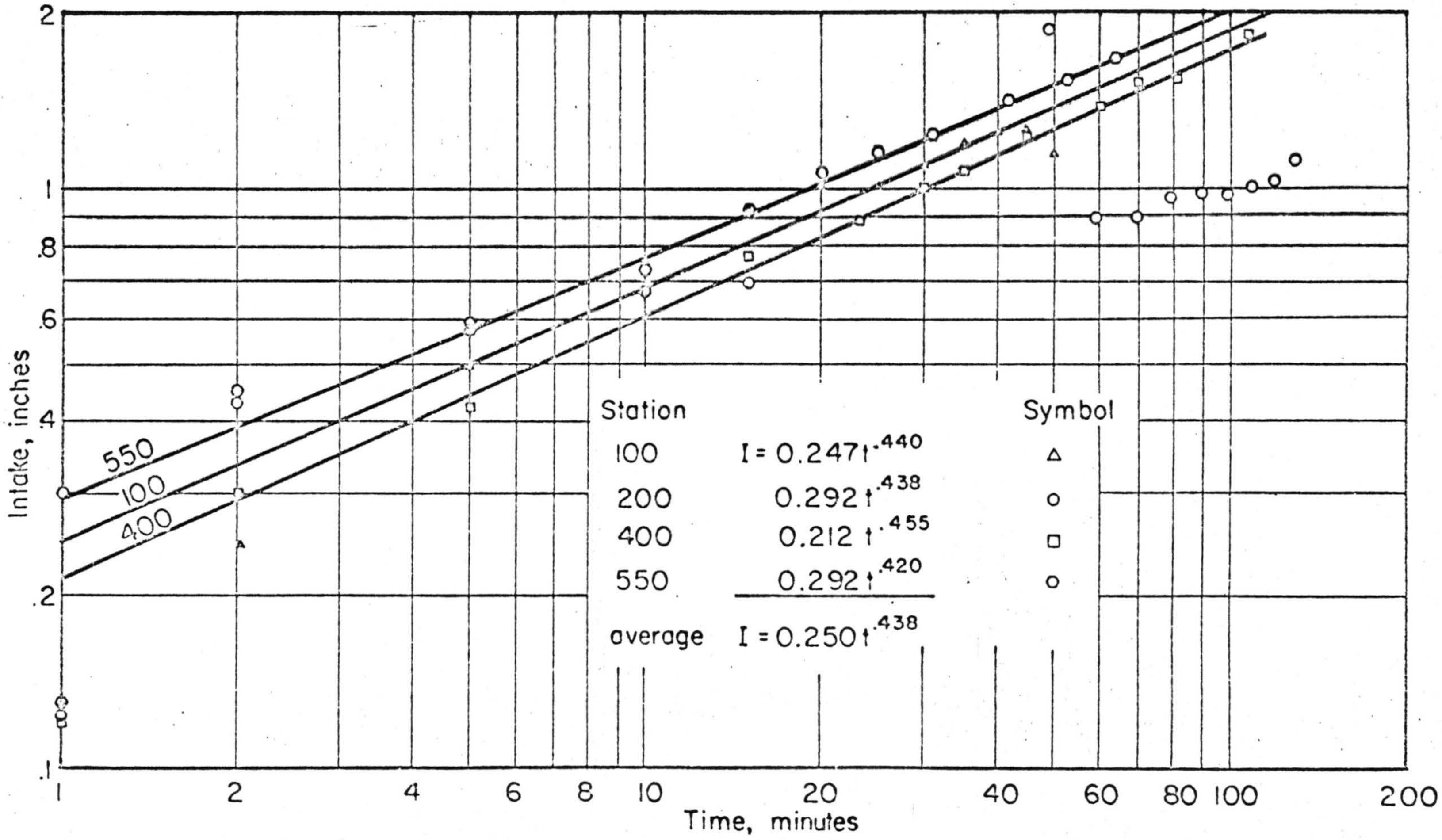


Fig. 25. Accumulated Intake at Four Stations on Border 25 obtained by Cylinder Infiltrometers.

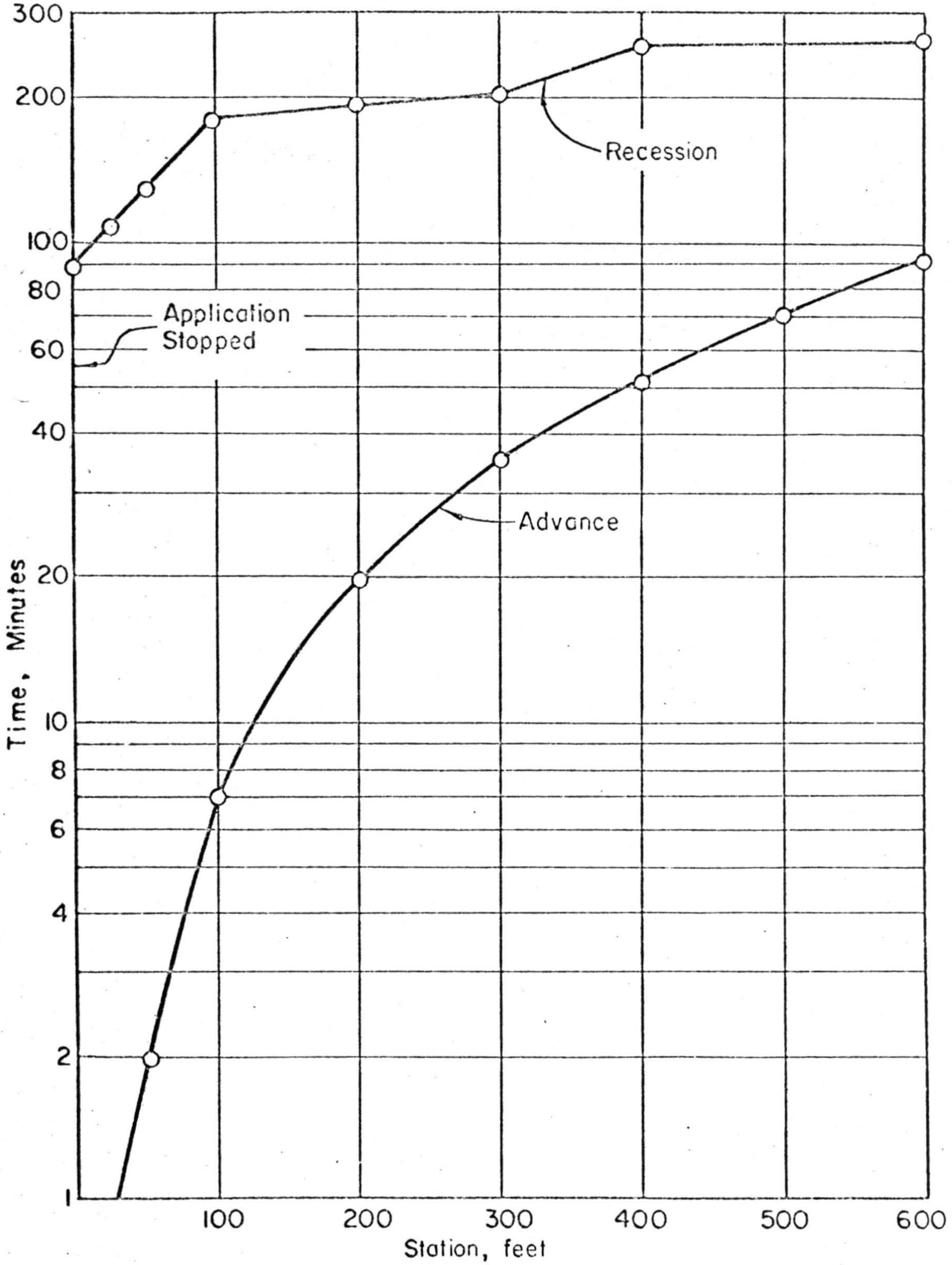


Fig. 26. Rates of Advance and Recession - Border 25 - August 30, 1967.

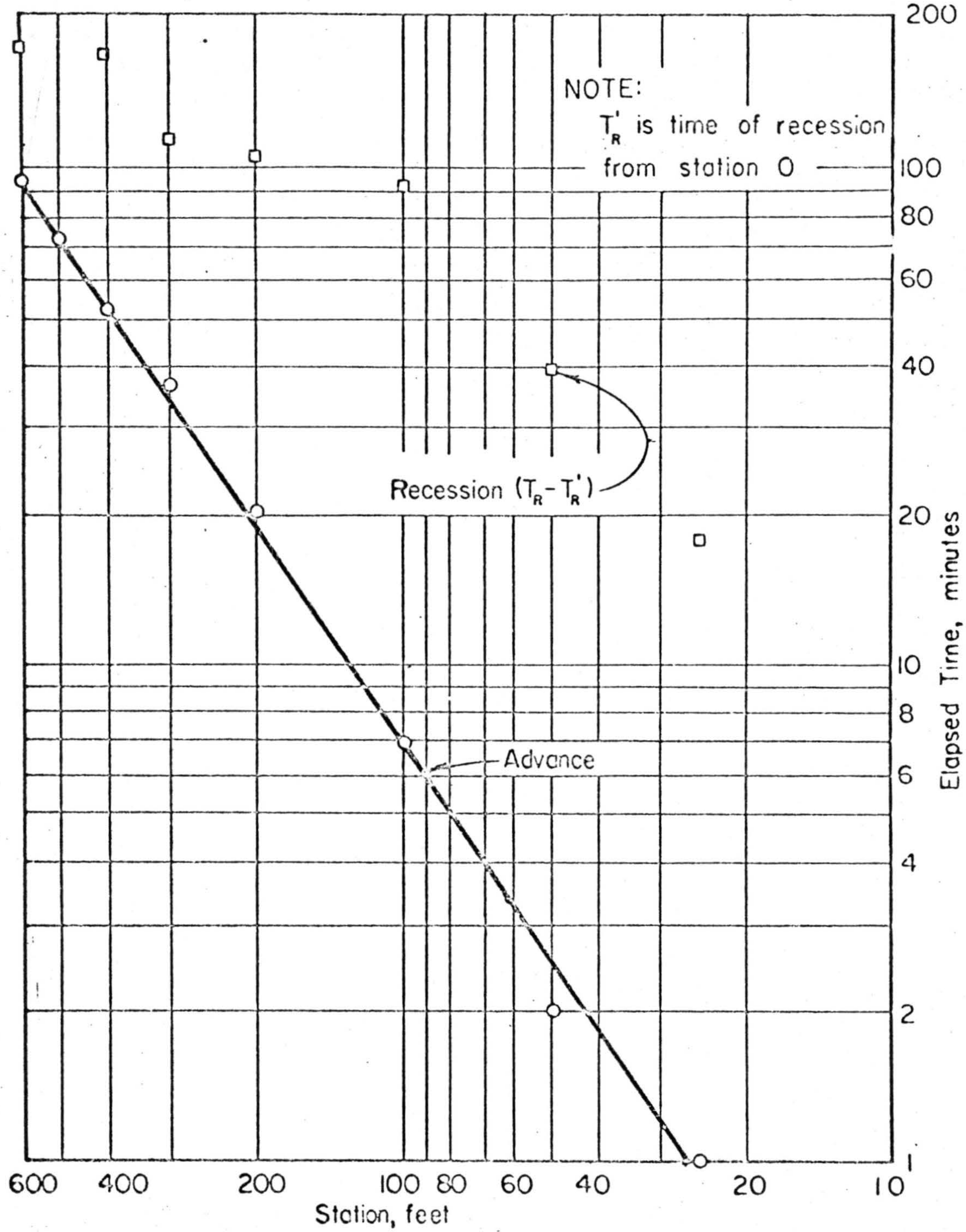


Fig.27. Advance and Corrected Recession Times - Border Y - August 30, 1967.

wide border at a rate of 2.4 cfs (0.0506 cfs/foot). Time of application was 55 minutes. Fig. 25 shows cumulative infiltration measured by each of four cylinders. Cylinders at 100, 400, and 550 foot stations gave readings that were apparently reliable and in close agreement. Piping developed at the 200-foot cylinder sometime between 5 and 60 minutes after the test was started. A representative intake equation for this date for the entire border is:

$$I = 0.250\ t^{0.438}$$

where I is cumulative intake, inches, and t is elapsed time in minutes.

Figures 26 and 27 show the advance and recession of the water stream plotted as a function of time on log-log and semilog graphs. Intake opportunity time at any distance down the border can be estimated from Figure 26 from the distance between the two curves. Recession data are quite erratic, largely because irregularities of border slope cause ponding in places and recession time is overestimated. The elapsed time between recession at each station on the border and the recession of the surface stream from Station 0 is shown as $TR-TR_0$ in Figure 27. Some researchers have suggested that this relation will be linear on a log-log plot. The scatter of data is too great for linearity to be proven in Figure 27. For the 8-1-67 irrigation of Border Y, this linearity was well defined for stations 0 to 400.

"Hydrographs" or plots of surface water depth versus time were developed but are not shown. These plots can be used to interpolate depths that occurred between measurement times. They also illustrate the maximum depth at each station and the rapid decrease in depth after inflow to the border is stopped.

Table 5 is an example of the computation of volumes of water applied, water in surface storage and water infiltrated at different time intervals after the start of the irrigation. The initial time intervals correspond with the times that the advancing stream reached each 100 foot station. Volumes can be compared at the end of each time interval to determine the error in the analysis to that point. After surface water recedes from a station, the volume infiltrated at that station remains unchanged and the surface storage volume drops to zero. Runoff volumes can also be determined as a function of time from flume recorder charts and added to the volume balance equation.

Finally, after all water has receded from the surface, the volume infiltrated should equal the volume applied less the volume of runoff. In the example shown, these volumes differed by only 1.4 percent. For most borders the variation was greater, as much as 30 percent in one case.

From the hydraulics measurements on each border, exponential equations were developed for advance distance, recession distance and accumulated infiltration as a function of time. As previously noted, scatter of some of the recession data causes them to be poorly characterized by the equations. The variability of advance, recession and intake for different borders on the same field and for irrigation at different times of the season were shown by these equations. The coefficients of the advance equation:

$$L = at^b$$

are related to discharge onto the border, Figure 28. No trends for variation of recession with discharge slope, etc. were established.

Table 5 - Border Hydraulics Analysis

Border Y
August 30, 1967
Intake, I = $0.250t^{.438}$

Border Width = 47.51
Application Time = 55 minutes
Application Rate = 2.4 cfs

Station	25	75	125	175	225	275	325	375	425	475	525	575	625
Time of Advance	1	4	10	16	24	32	40	48	56	66	76	88	100
t = 7 min.													
t_o	6	3											
$t_o^{.438}$	2.192	1.618											
I"	.548	.404											
I'	.046	.034											
V_I	109.2	80.7											
d	.25	.16											
V_s	593.7	380.0											
t = 20 min.													
t_o	19	16	10	4									
$t_o^{.438}$	3.63	3.37	2.74	1.835									
I"	.907	.842	.685	.459									
I'	.075	.070	.057	.038									
V_I	178.1	166.2	135.4	90.2									
d	.35	.37	.25	.13									
V_s	831.2	878.7	593.7	308.7									
t = 36 min.													
t_o	35	32	26	20	12	4							
$t_o^{.438}$	4.74	4.56	4.17	3.71	2.97	1.835							
I"	1.185	1.140	1.042	.927	.742	.959							
I'	.099	.095	.087	.077	.062	.038							
V_I	235.1	225.6	206.6	182.9	147.2	90.2							
d	.41	.46	.40	.34	.22	.13							
V_s	973.7	1092.5	950.0	807.5	522.5	308.7							

t = time elapsed since application started

t_o = time water has been on station

I" & I' = Accumulated intake, inches and feet, resp.

V_I = Volume infiltrated at station, ft^3

d = Depth of surface flow at time t, feet

V_s = Volume of surface storage at station, ft^3

t = 7 min.:
ΣV_I 189.9
ΣV_s 973.7
1163.6 ft^3

t = 20 min.:
ΣV_I 569.9
ΣV_s 2612.3
3182.2 ft^3

t = 36 min.:
ΣV_I 1087.6
ΣV_s 4654.9
5742.5 ft^3

Table 5 (cont)

Station	25	75	125	175	225	275	325	375	425	475	525	575	625		
Time of Advance	1	4	10	16	24	32	40	48	56	66	76	88	100		
t = 52 min.															
t_o	51	48	42	36	28	20	12	4							
$t^{.438}$	5.6	5.45	5.14	4.8	4.3	3.71	2.97	1.835							
I"	1.40	1.36	1.28	1.20	1.07	.927	.742	.459							
I'	.117	.113	.107	.100	.089	.077	.062	.038							
V_I	277.9	268.4	254.1	237.5	211.3	182.9	147.2	90.2						Σ V_I	1669.5
d	.44	.50	.48	.44	.36	.32	.21	.07						Σ V_s	6697.4
V_s	1045.0	1187.5	1140.0	1045.0	855.0	760.0	498.7	166.2							8366.9 ft^3
t = 72 min.															
t_o	71	68	62	56	48	40	32	24	16	6					
$t^{.438}$	6.46	6.35	6.10	5.82	5.45	5.03	4.56	4.02	3.37	2.192					
I"	1.615	1.587	1.525	1.455	1.362	1.257	1.14	1.005	.842	.548					
I'	.134	.132	.127	.121	.113	.105	.095	.084	.070	.046					
V_I	318.2	313.5	301.6	287.4	268.4	249.4	225.6	199.5	166.2	109.2				Σ V_I	2439.0
d	.15	.29	.34	.33	.32	.32	.30	.28	.18	.09				Σ V_s	6174.8
V_s	356.2	688.7	807.5	783.7	760.0	760.0	712.5	665.0	427.5	213.7					8613.8 ft^3
t = 94 min.															
t_o	93	90	84	78	70	62	54	46	38	28	18	6			
$t^{.438}$	7.29	7.18	6.96	6.64	6.44	6.10	5.74	5.35	4.92	4.3	3.55	2.192			
I"	1.822	1.795	1.740	1.660	1.660	1.525	1.435	1.337	1.320	1.07	.887	.548			
I'	.152	.149	.145	.138	.134	.127	.119	.111	.102	.089	.074	.046			
V_I	361.0	353.9	344.4	327.7	318.2	301.6	282.6	263.6	242.2	211.3	175.7	109.2		Σ V_I	3291.4
d	.04	.16	.23	.23	.24	.24	.27	.26	.22	.16	.07	.04		Σ V_s	5129.8
V_s	95.0	380.0	546.2	546.2	570.0	570.0	641.2	617.5	522.5	380.0	166.2	95.0			8421.2 ft^3

Table 5 (cont)

Station	25	75	125	175	225	275	325	375	425	475	525	575	625	
Time of Advance	1	4	10	16	24	32	40	48	56	66	76	88	100	
t = 124 min.														
t_o	114	120	114	108	100	92	84	76	68	58	48	36	24	
$t_o^{.438}$	7.95	8.15	7.95	7.76	7.52	7.25	6.96	6.66	6.35	5.91	5.45	4.8	4.02	
I''	1.987	2.037	1.987	1.940	1.880	1.812	1.740	1.665	1.587	1.477	1.362	1.20	1.005	
I'	.165	.170	.165	.162	.157	.151	.145	1.39	.132	.123	.113	.100	.084	
V_I	391.9	403.7	391.9	384.7	372.9	358.6	344.4	330.1	313.5	292.1	268.4	237.5	239.4	ΣV_I 4329.1
d	0	.09	.142	.150	.155	.165	.20	.22	.205	.15	.122	.130	.10	ΣV_s 4438.6
V_s		213.7	337.2	356.2	368.1	391.9	475.0	522.5	486.9	356.2	289.7	308.7	285.0	8767.7 ft^3
t = 183 min.														
t_o		198	173	167	159	151	143	135	127	117	107	95	83	
$t_o^{.438}$		8.92	9.55	9.40	9.20	9.00	8.90	8.56	8.35	8.05	7.75	7.35	6.92	
I''		2.230	2.387	2.350	2.30	2.250	2.225	2.140	2.087	2.012	1.937	1.837	1.730	
I'		.186	.198	.196	.192	.187	.185	.178	.174	.168	.161	.153	.144	
V_I	391.9	441.7	470.2	465.5	456.0	444.1	439.4	422.7	413.2	399.0	382.4	363.4	410.4	ΣV_I 5499.9
d			.01	.02	.04	.06	.085	.11	.12	.08	.05	.09	.16	ΣV_s 2035.2
V_s			23.7	47.5	95.0	142.5	201.9	261.2	285.0	190.0	118.7	213.7	456.0	7535.1 ft^3
t = 193 min.														
t_o			175	173	169	161	153	145	137	127	117	105	93	
$t_o^{.438}$			9.60	9.55	9.45	9.25	9.05	8.95	8.62	8.35	8.05	7.69	7.29	
I''			2.40	2.387	2.362	2.312	2.262	2.212	2.155	2.087	2.012	1.922	1.822	
I'			.20	.199	.197	.193	.188	.184	.179	.174	.168	.160	.152	
V_I	391.9	441.7	475.0	472.6	467.9	458.4	446.5	437.0	425.1	413.2	399.0	380.0	433.2	ΣV_I 5641.5
d			0	0	.025	.045	.075	.10	.105	.072	.05	.085	.15	ΣV_s 1750.4
V_s					57.4	106.9	178.1	237.5	249.4	171.0	118.7	201.9	427.5	7391.9 ft^3

Table 5 (cont)

	Station														
	25	75	125	175	225	275	325	375	425	475	525	575	625		
	Time of Advance														
	1	4	10	16	24	32	40	48	56	66	76	88	100		
t = 206 min.															
t_o					172	170	166	158	150	140	130	118	106		
$t_o^{.438}$					9.52	9.49	9.38	9.16	8.99	8.71	8.43	8.08	7.71		
I"					2.38	2.372	2.345	2.29	2.247	2.177	2.107	2.02	1.927		
I'					.198	.198	.195	.191	.187	.181	.175	.168	.160		
V_I	391.9	441.7	475.0	472.6	470.2	470.2	463.1	453.6	444.1	429.9	415.6	399.0	456.0	ΣV_I	5782.9
d					0	0	.034	.09	.10	.075	.04	.08	.14	ΣV_s	1394.0
V_s							80.7	213.7	237.5	178.1	95.0	190.0	399.0		7176.9 ft^3
t = 226 min.															
t_o							186	178	170	160	150	138	126		
$t_o^{.438}$							9.86	9.66	9.47	9.24	8.99	8.65	8.31		
I"							2.465	2.415	2.372	2.31	2.247	2.162	2.077		
I'							.205	.201	.198	1.92	.157	.180	.173		
V_I	391.9	441.7	475.0	472.6	470.2	470.2	486.9	477.4	470.2	456.0	453.6	427.5	493.0	ΣV_I	5986.2
d							.025	.08	.075	.04	.015	.06	.12	ΣV_s	1042.6
V_s							59.4	170.0	178.1	95.0	35.6	142.5	342.0		7028.8 ft^3
t = 257 min.															
t_o							178	198	201	182	160	169	157		
$t_o^{.438}$							9.66	10.15	10.20	9.71	9.24	9.45	9.15		
I"							2.415	2.537	2.55	2.447	2.31	2.362	2.287		
I'							.201	.211	.212	.204	.192	.197	.190		
V_I	391.9	441.7	475.0	472.6	470.2	470.2	477.4	501.1	503.5	484.5	456.0	467.9	541.5	ΣV_I	6153.5
d							0	0	.005	0	0	.005	.03	ΣV_s	109.3
V_s									11.9			11.9	85.5		6262.8 ft^3

Table 5 (cont)

	Station														
	25	75	125	175	225	275	325	375	425	475	525	575	625		
	Time of Advance														
	1	4	10	16	24	32	40	48	56	66	76	88	100		
t = 262 min.															
t_o									203			170	162		
$t_o^{.438}$									10.25			9.49	9.30		
I"									2.562			2.372	2.325		
I'									.213			.198	.194		
V_I	391.9	441.7	475.0	472.6	470.2	470.2	477.4	501.0	505.9	484.5	456.0	470.2	552.9	ΣV_I	6169.6
d^I													.02	ΣV_s	57.0
V_s													57.0		6226.6 ft^3
t = 303 min.															
t_o													171		
$t_o^{.438}$													9.50		
I"													2.375		
I'													.198		
V_I	391.9	441.7	475.0	472.6	470.2	470.2	477.4	501.0	505.9	484.5	456.0	470.2	564.3	ΣV_I	6181.0 ft^3
d^I															
V_s															

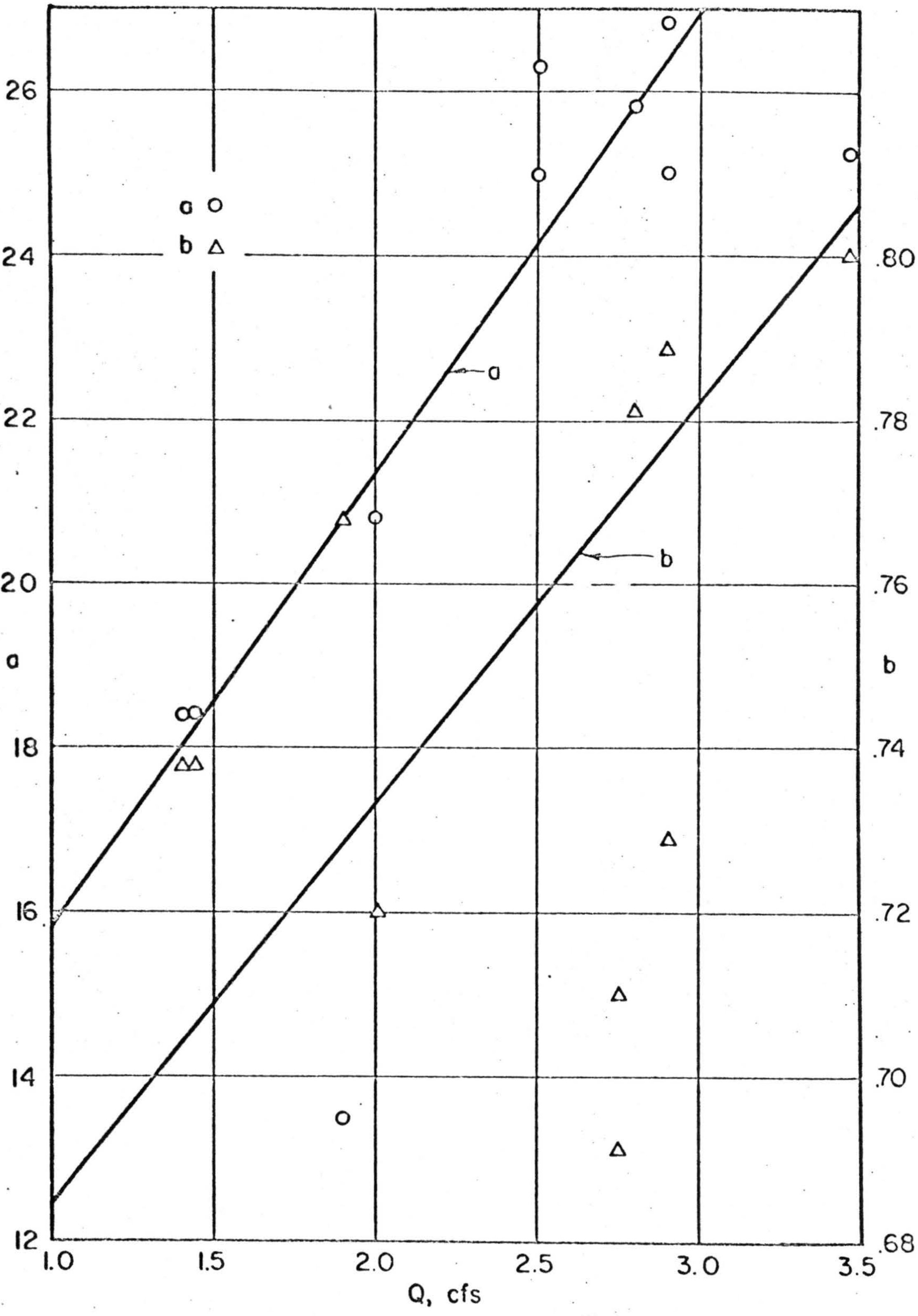


Fig. 28. Advance Equation Coefficients as Related to Discharge where Advance of Wetting Front, $L = at^b$.

Upper Bench Root Development

Figure 29 shows photographs of pits on field 7, on the 18th and 22nd borders from the west side of the field and 150 feet downstream from the ditch and 200 feet upstream from the road, respectively. (This is an area where soils were cut as much as 3 feet in grading the soils for border irrigation.) Top-soil depth varies from 0 to 4 inches in these pits; root depth did not exceed 18 inches. In Figure 29 horizontal root growth is indicated by the pencil.

Field 7 was one on which most top soil had been removed in spots, in the process of land grading to prepare for border irrigation. The roots shown in Figure 29 represent three years' growth on areas of this field where the most severe soil removal had occurred.

For comparison, root profiles from the center pivot irrigated field are pictured in Figure 30. No cuts or fills were made in the process of preparing this field for irrigation.

Much better soil conditions were found on the sprinkler field. Near the sprinkler pivot, 3 feet of soil depth was observed with roots penetrating to 18 inches, after 6 months, Figure 30. Two feet of soil and the same root penetration occurred near the southeast edge of the field.

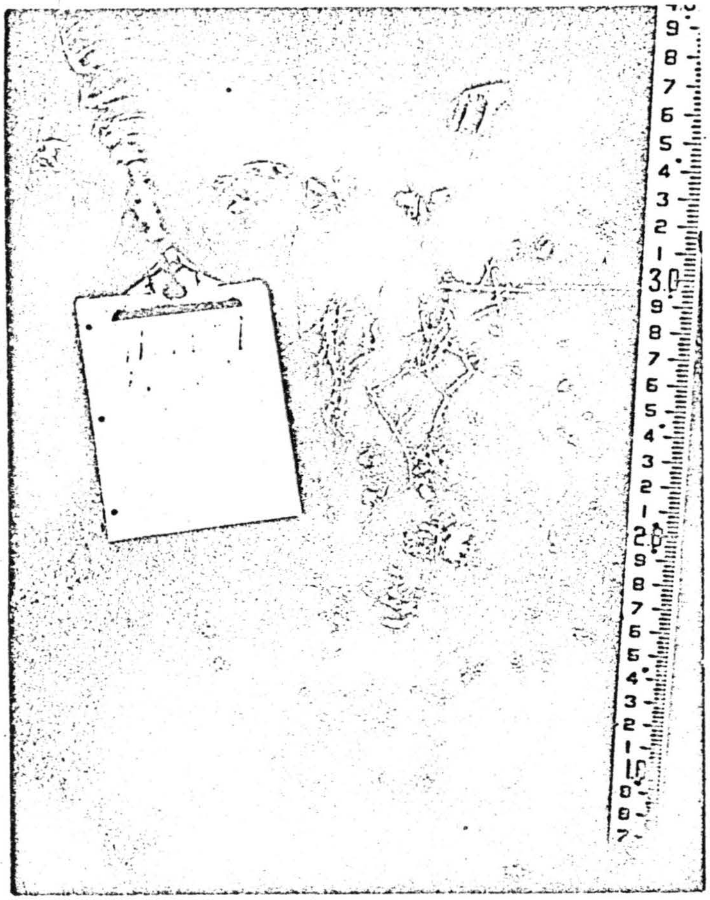
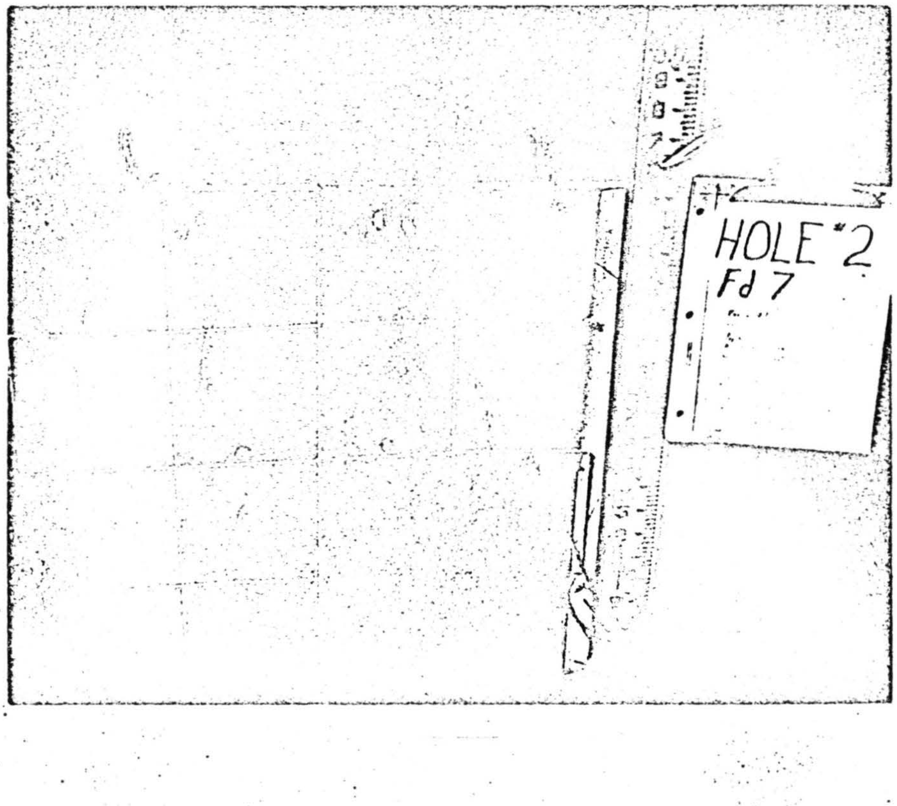


Fig. 29.--Soil and root profiles in deep cut areas on Field 7, Seekskadee Development Farm.

	Hole #1
Top soil depth	4"
Alfalfa root depth	12"
Grass root depth	12"

	Hole #2
Top soil depth	0
Alfalfa root depth	18"
Grass root depth	10-12"



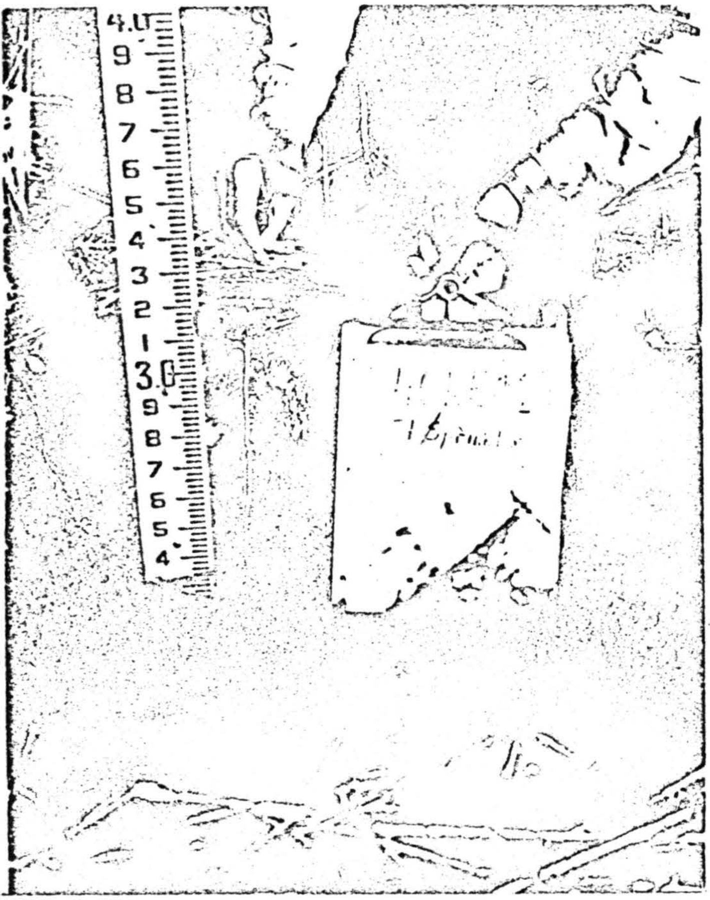
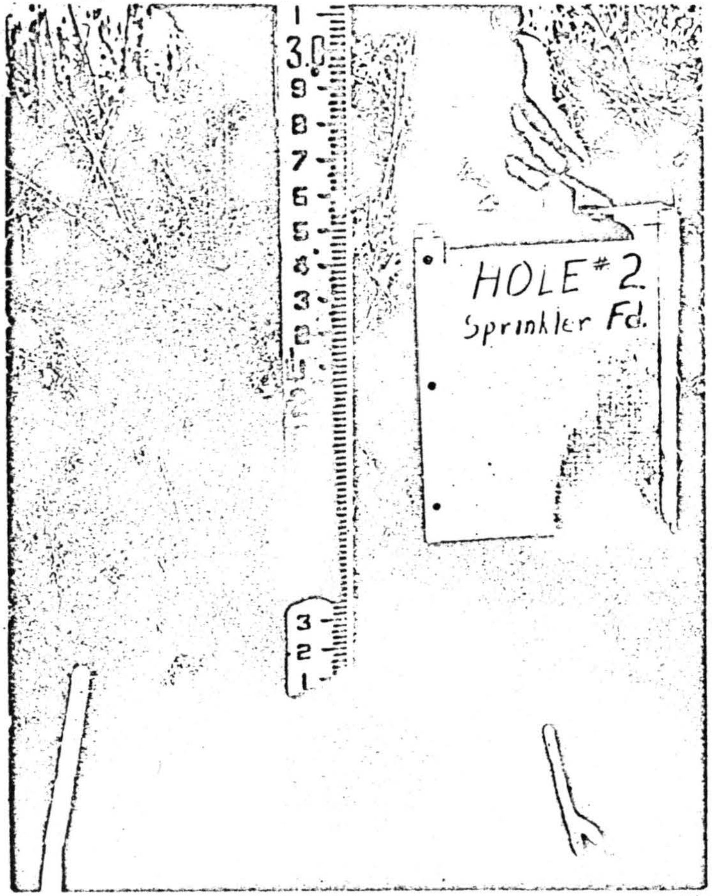


Fig. 30.--Soil and root profile on self-propelled sprinkler field, Seedskadee Development Farm. Shallow-root penetration due to immaturity of crop.

	Hole #1
Top Soil Depth	36"
Alfalfa root depth	12-18"
Grass root depth	8"



	Hole #2
Top soil depth	24"
Alfalfa root depth	12-18"
Grass root depth	8"

SUMMARY AND CONCLUSIONS

Methods of reducing irrigation labor requirements and efficiency of water applications were studied for three seasons on the Seedskadee Development Farm. The methods of irrigation included diked borders with automated turnouts from open ditches, contour ditches using a motorized irrigator to divert water from the ditches, contour dikes equipped with semiautomatic gates and a side roll sprinkler lateral. Water applied and running off each field was measured for each irrigation. Soil water changes were measured in representative areas on the deeper soils. During the last season of study, detailed data on stream advance, recession and infiltration were obtained for three borders on the upper bench.

The following conclusions can be drawn from the study:

1. Reasonable yields of grasses and legumes (up to 4.5 tons/acre/ year) can be produced on Seedskadee lower bench soils with adequate fertilization and irrigation.

2. Borders on lower bench field 10 were too narrow for effective hay harvesting. All borders should be spaced at some even multiple of harvesting equipment width. Maximum width will depend upon depth of soil that can be cut in removing border-cross slope.

3. Some variation in logitudinal slope of borders can be allowed. However, no adverse grades can be permitted. Abrupt changes from low to high slopes will cause the irrigation stream to form channels and erode soil during irrigation prior to crop establishment.

4. Effective use of the modified Power Dike Irrigator was prevented by problems related to poor traction, alignment with field lateral and plugging of auger, when use on the rocky, unlined ditches, characteristic

of the lower bench soils found on the Seedskadee Development Farm.

5. A side-roll sprinkler lateral, 660 feet long, did a good job of irrigating a ten-acre low-bench field, when managed properly. Such management includes 12 to 16 hours operation per day during peak water use periods, short interruptions of irrigation for hay harvesting and provision of a sediment-free intake for the sprinkler pump.

6. Use of contour dikes with semiautomatic gates did not adequately distribute water on lower bench field 13 and are not recommended. Problems included difficulty in synchronizing the trip mechanisms on the gates and slow surface drainage from irrigated benches to dry benches when gates were opened. Over irrigation of upper benches (near the supply ditch) and under irrigation of lower benches resulted.

7. No more water should be applied to lower bench lateral at any one time than is necessary to supply fields being irrigated at that time. Even so, much water will be lost as seepage from the lateral, causing high water table problems in lower bench fields.

8. Water releases from 15-inch pipe turnouts on upper bench can be automated with lay-flat pneumatic valves and associated controls. However, more recent research at other locations has resulted in the development of a more practical system using plastic hydraulic cylinders and controls to open and close turnouts.

9. Uniformity coefficients of water distribution on the borders averaged nearly 80 percent.

10. Runoff, measured from individual borders, ranged from 0 to 35 percent of the water applied. The average value, in 1967, was 8.9 percent.

11. Water application efficiencies of upper bench borders could not be determined because of inability to get accurate measurements of soil water changes by irrigation. Deep percolation losses were small, as indicated by the reasonably high coefficients of uniformity. Therefore, good application efficiencies, 60 to 70 percent, can be assumed.

12. No consistent difference in runoff amounts or irrigation efficiencies was noticed as border length varied from 600 to 850 feet.

13. Rate of advance varies with the size of irrigation stream applied to the border. The variation can be expressed by the empirical relation:

$$L = at^b$$

where:

$$a = 10 + 5.7\,Q$$
$$B = 7.7 + 4.9\,Q$$

and Q is the discharge, cfs, onto a 50-foot wide border

14. Intake for any one border at any given date can be determined by cylinder infiltrometers and represented by an equation of the form $I = at^b$.

15. Runoff can be reduced and uniformity of distribution increased by border dike layout such as exists on main part of development farm. The borders are blocked at the downstream end, preventing runoff directly to a drainage ditch. The dikes, however, end several feet short of the ends of the borders. Potential runoff, resulting from small variations in intake rate or volume of water applied, therefore must flow across the ends of other borders, supplementing the irrigations on those where inadequate water was applied.

APPENDIX.--Climatic Measurements, Seedskadee Development Farm, Fontanelle, Wyoming[1]

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
6/8/65								
9					0.77			
10					0.11			
11					0.12			
12								
13					0.84&Hail			
14					0.12			
15					Trace			
16				6.47				
17			78	7.99	0.04	0.17		
18	59	37	62	4.98	Trace&Hail	0.13		
19	68	36	50	3.09		0.14		
20	70	36	52	5.12		0.36		
21	70	43	75	5.25		0.18		
22	73	44	54	6.68		0.60		
23	76	42	56	4.62	Trace	0.42		
24	78	50	92	3.50	0.01	0.47		
25	60	45	77	8.23	0.06	0.26		
26	64	41	58	5.96	0.04	0.17		
27	61	43	59	7.50	0.01	0.28		
28	60	36	62	4.38		0.25		
29	65	39	58	3.84		0.30		
30	70	43	51	3.45		0.33		
Ave.	67.2	41.2	63.1	5.40	0.10	0.29		

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[1] Tabulated values represent measurements taken during 24 hours prior to 8:00 A.M. on the date recorded. Some wind velocity, solar radiation and evaporation values are averages for two or three day periods.

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
Date	Max.	Min.					Langleys	Evaporation Equiv., in.
7/1/65	78	42	52	3.15		0.26		
2	76	40	59	6.13		0.69		
3	70	41	52	3.70		0.44		
4	73	43	54	3.61		0.28		
5	79	45	58	3.15		0.50		
6	78	41	16	4.43		0.41		
7				2.42		0.42		
8				4.37	0.04	0.25		
9				3.44		0.47		
10				5.13				
11				5.13	0.04	0.38		
12				5.25		0.39		
13	73	38	46	4.80		0.59		
14	78	42	36	3.15		0.38		
15	82	45	39	2.17		0.43		
16	83	46	48	2.72		0.42		
17	82	52	46	2.20		0.42		
18	80	56	84	7.09	0.03	0.39		
19	77	55	91	2.25	0.29	0.49		
20	76	52	72	3.03	0.11	0.12		
21	76	48	66	3.50	Trace	0.20		
22	81	59	62	4.12		0.48		
23	78	52	76	4.49		0.40		
24	79	50	63	2.56		0.32		
25	79	55	90	3.60	Trace	0.31		
26	74	46	98	2.43	Trace	0.26		
27	77	46	52	2.75		0.33		
28	80	50	50	2.80		0.41		
29	84	52	46	1.48		0.31		
30	86	60	51	2.60	Trace	0.37		
31	73	53	76	3.35	0.04	0.26		
Ave.	78.1	48.4	59.3	3.58		0.38		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F Max.	Air Temperature, °F Min.	Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipi- tation (in.)	Evapo- ration (in.)	Total Solar Radiation Langleys	Total Solar Radiation Evaporation Equiv., in.
8/1/65	70	44	49	2.83		0.22		
2	76	44	44	1.59		0.32		
3	78	51	52	2.60		0.37		
4	78	45	67	4.00	0.01	0.41		
5	76	42	53	3.38		0.34		
6	75	39	55	4.24		0.40		
7	76	39	68	3.69		0.44		
8	79	46	66	2.14		0.66*		
9	84	47	44	2.00		0.34		
10	85	52	58	2.61		0.30		
11	83	50	58	2.66		0.39		
12	84	49	63	2.08		0.36		
13	85	49	72	3.37		0.37		
14	78	47	52	2.73		0.29		
15	76	48	72	1.48		0.29		
16	78	43	60	2.00		0.19		
17	79	46	47	1.60		0.33		
18	76	50	54	1.01		0.21		
19	74	52	87	2.13		0.58		
20	65	45	70	2.83	0.07	0.15		
21	70	48	78	1.71	0.06	0.06		
22	61	41	82	1.85	0.08	0.08		
23	70	44	50	1.61	Trace	0.02		
24	66	39	79	3.65		0.29		
25	72	42	67	2.73		0.19		
26	76	38	46	4.51		0.50		
27	70	40	66	3.10		0.34		
28	78	41	48	1.90		0.31		
29	78	44	42	3.71		0.41		
30	66	36	33	3.76		0.34		
31	64	29	59	2.52		0.21		
Ave.	75.0	43.9	59.4	2.65		0.31		

*Includes 0.48 in. sprinkled into the evap. pan.

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min					Langleys	Evaporation Equiv., in.
9/1/65	68	31	61	2.18		0.25		
2	72	35	63	2.60		0.31		
3	72	39	68	3.70		0.26		
4	70	35	38	5.80		0.37		
5	66	39	46	3.30		0.28		
6	64	43	87	3.56	0.52	0.63		
7	53	42	87	2.12	0.10	0.10		
8	66	43	86	1.92	0.09	0.09		
9	63	36	74	4.50		0.00		
10	61	34	72	2.20		0.15		
11	70	36	62	2.74		0.19		
12	69	38	68	3.22		0.27		
13	70	34	60	4.26		0.31		
14	70	43	45	5.05		0.43		
15	60	43	67	6.18		0.35		
16	59	22	91	7.26	0.24	0.39		
Ave.	65.8	37.1	67.2	3.79	0.06	0.27		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipi- tation (in.)	Evapo- ration (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
5/2/66	69							
3	72	30	73					
4	74	30	64	2.20				
5	75	35	69	2.57				
6	76	36	74	3.73				
7	75	39	87	4.27				
8	70	36	96	4.30	.28			
9	67	38	77	4.31			204	.14
10	46	28	68	7.07			472	.32
11	42	26	80	8.86			548	.37
12	51	34		6.81				
13	54	34		1.70				
14	58	34		1.70				
15	61	36		1.70				
16	62	32		1.70				
17	56	32		1.70				
18	62	28	43	4.15			716	.48
19	66	34	29	5.80			711	.48
20	70	38	36	4.57			681	.46
21	74	41	24	8.73			544	.36
22	43	23	34	10.67			--	--
23	58	29	70	3.73			727	.48
24	70	33		2.81			713	.48
25	74	34		2.41			--	--
26	76	40	39	2.24			733	.49
27	78	42	37	3.12			684	.46
28	78	44		3.51			647	.43
29	79	40	46	2.34			586	.39
30	79	40		5.07			667	.44
31	70	48		5.85			344	.23
Ave.	64.0	32.7		4.34				

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipi- tation (in.)	Evapo- ration (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
6/1/66	74	32	36	3.63			--	--
2	76	35		4.25			--	--
3	73	37		7.67			733	.49
4	62	31		7.41			--	--
5	64	31		3.25			--	--
6	67	42		4.05			469	.31
7	65	43	55	3.72	.61		284	.19
8	62	44	62	2.75			408	.27
9	68	40	62	3.13			427	.28
10	68	46	60	8.59	.03	.59	--	--
11	59	42	36	7.58		.49	--	--
12	60	31	35	4.74			681	.46
13	68	31	41	5.43			668	.45
14	74	39	35	6.17			649	.43
15	76	42	48	5.12	.05		606	.40
16	65	42	58	3.74		.24	550	.37
17	77	48	61	2.87		.31	533	.36
18	79	44	46	3.17		.26	515	.34
19	81	45	46	2.97		.39	557	.37
20	81	44	42	3.69		.39	541	.36
21	78	52	54	3.46	.04	.11	316	.21
22	63	44	61	5.17		.29	458	.31
23	68	36	54	3.05		.32	514	.34
24	66	44	50	5.57		.29	608	.41
25	70	33	30	1.79		.47	688	.46
26	84	43	35	3.36		.47	--	--
27	85	44		2.83		.46	650	.43
28	85	44	32	2.62		.38	--	--
29	86	50	39	2.71		.43	--	--
30	81	51	36	4.15	.45	.42	--	--
Ave.	72.1	41.0	35.8	4.62		.35		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
7/1/66	70	51	83	1.84	.50		479	.13
2	81	51	43	5.10		.41	479	.13
3	80	44	43	2.53		.39	479	.13
4	82	55		4.25		.49	692	.18
5	83	44	43	3.66		.50	695	.18
6	89	43	44	2.09		.38	695	.18
7	89	47	44	4.65		.45	--	--
8	82	56	21	5.40		.50	--	--
9	85	44	38	3.68		.40	515	.14
10	77	51	55	2.56		.36	325	.09
11	79	53	43	3.52		.42	399	.10
12	82	54	49	2.42	.04	.16	472	.12
13	85	48	49	2.24		.25	646	.17
14	85	48	49	2.24		.67	672	.18
15	89	48	22	1.96		.47	618	.16
16	84	50	26	3.63		.40	495	.13
17	88	51	42	3.48		.43	519	.14
18	90	54	42	3.48		.42	600	.16
19	90	54	41	2.17		.37	453	.12
20	90	52	40	2.38		.42	560	.15
21	73	57	32	2.44		.25	330	.09
22	84	48	51	3.24		.40	490	.13
23	87	51	40	3.06		.40	612	.16
24	88	50	40	2.29		.28	492	.13
25	87	51	45	3.12		.52	585	.15
26	86	58	40	4.31		.34	423	.11
27	88	51	45	3.32		.37	520	.14
28	90	52	40	2.09		.47	598	.16
29	90	50	47	3.34		.48	598	.16
30	92	49	41	2.63		.48	598	.16
31	83	62	50	4.33		.45	481	.13
Ave.	84.8	50.9	41.2	3.16		.40		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F Max.	Air Temperature, °F Min.	Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation Langleys	Total Solar Radiation Evaporation Equiv., in.
8/1/66	86	62	58	3.92		.34	475	.32
2	84	56	53	2.25		.28	403	.27
3	75	54	65	2.00		.12	302	.20
4	78	52		3.11		.14	613	.41
5	82	56	47	1.62		.34	536	.36
6	82	50	49	2.80		.47	624	.42
7	82	49	53	4.04		.44	554	.37
8	79	50	44	3.86		.47	602	.40
9	78	49	42	3.98		.46	590	.39
10	82	46	44	3.80		.42	596	.40
11	81	47	30	3.31		.48	567	.38
12	75	51	50	5.01	.04		559	.37
13	80	40	34	3.62			607	.40
14	78	48	20	3.62		.35	603	.40
15	84	40	32	3.62		.43	605	.40
16	84	44	33	3.27		.42	535	.36
17	85	45	32	3.03		.35	466	.31
18	78	49	31	2.05		.27	310	.21
19	77	48	50	3.06		.28	422	.28
20	73	41	42	2.77		.39	484	.32
21	70	34	44	4.62		.31	581	.39
22	70	36	44	2.32		.27	517	.34
23	77	44	39	1.75		.25	557	.37
24	80	42	39	.92		.30	571	.38
25	82	45	38	1.52		.29	566	.38
26	81	40	36	1.39		.33	411	.27
27	70	34	37	4.22		.29	561	.37
28	79	42	50	3.57		.27	546	.36
29	81	45	33	1.70		.41	495	.33
30	74	48	42	3.77	.02	.26	400	.27
31	69	48	58	3.41	.02	.20	392	.26
Ave.	78.5	46.2	40.7	3.03		.31		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
9/1/66	63	45	71	3.34		.19	219	.15
2	63	41	68	2.67	.05	.07	348	.23
3	73	35	70	2.25	.01	.23	537	.36
4	78	42	64	1.21		.30	521	.35
5	80	42	60	1.93		.28	297	.20
6	79	40	46			.27	297	.20
7	80	40	50			.28		
8	82	40	44			.26		
9	82	42	50			.37		
10	76	45	44			.37		
Ave.	79.8	41.4	46.8			.29		

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
Winter Temperatures, 1966								
9/11	71	45						
12	69	45						
13	68	43						
14	63	34						
15	47	35						
116	60	34						
17	73	40						
18	77	42						
19	80	41						
20	78							
10/ 3	46	22						
4	53	25						
5	63	28						
6	65	31						
7	67	36						
8	62	33						
9	60	21						
10	64	31						
11	64	30						
12	60	32						
13	35	8						
14	30	12						
15	28	14						
16	34	14						
17	40	21						
18	38	16						
19	46	21						
20	50	28						
21	34	20						
22	42	30						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
10/23/66	50	27						
24	61	25						
25	57	26						
26	63	28						
27	62	26						
28	58	28						
29	60	23						
30	59	38						
31	56	17						
11/ 1/66	48	24						
2	58	20						
3	56	19						
4	47	28						
5	53	28						
6	52	30						
9	27	23						
10	36	25						
11	42	31						
12	45	29						
13	51	25						
14	42	29						
15	44	27						
16	45	19						
17	46	26						
18	42	31						
19	42	16						
20	36	19						
21	39	25						
22	42	16						
23	36	7						
24	36	7						
25	40	16						
26	32	10						
27	40	18						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipi- tation (in.)	Evapo- ration (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
12/ 5/66	26	21						
6	28	16						
7	27	7						
8	21	-6						
9	15	-13						
10	22	6						
11	32	10						
13	29	5						
14	27	4						
15	29	-5						
16	20	-10						
17	19	-10						
18	14	-12						
19	14	5						
20	20	4						
21	16	-23						
22	8	-15						
1967								
1/ 2/67	23	8						
3	31	4						
4	36	27						
5	33	2						
6	16	-8						
7	13	-12						
8	25	4						
9	27	1						
10	30	-6						
11	28	22						
12	35	23						
13	33	13						
14	30	8						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F Max.	 Min.	Relative Humidity 0800, Percent	Wind Velocity Miles/ hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation Langleys	 Evaporation Equiv., in.
1/15/67	37	5						
16	24	8						
17	22	7						
18	23	6						
19	36	12						
20	37	23						
21	39	30						
22	38	21						
23	33	-5						
24	16	-13						
25	25	-4						
26	31	1						
27	37	13						
28	38	16						
29	39	24						
30	36	24						
31	34	3						
2/ 1/67	22	-1						
2	30	19						
3	34	20						
4	38	27						
5	28	-6						
16	24	14						
17	32	24						
18	34	1						
19	27	-12						
20	16	-7						
21	26	4						
22	28	6						
23	36	8						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
2/24/67	32	13						
25	38	18						
26	42	10						
27	-	7						
28	38	14						
3/ 1/67	48	30						
2	36	19						
3	36	22						
4	29	10						
5	28	18						
6	36	7						
7	24	15						
8	38	23						
9	49	28						
10	48	26						
11	46	28						
12	45	28						
13	43	21						
14	30	4						
15	36	17						
16	41	27						
17	46	29						
18	37	30						
19	39	23						
20	43	29						
21	44	24						
22	54	32						
23	55	33						
24	42	17						
25	43	26						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
3/26/67	42	30						
27	47	30						
28	58	35						
29	43	17						
30	27	10						
31	40	24						
4/ 1/67	40	19						
2	43	22						
3	55	25						
4	61	32						
5	45	22						
6	50	24						
7	58	25						
8	49	20						
9	50	22						

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature, °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
5/1/67	40	28						
2	42	24	47					
3	46	24	42					
4	52	24	47					
5	46	32	36					
6	54	29	43					
7	60	40	37					
8	66	42	24					
9	72	33	34					
10	56	37	46					
11	42	29	27					
12								
13								
14								
15								
16	66	32						
17	71	37						
18	70	37	41					
19	69	37	46		.08			
20	67	31	39				173	.11
21	76	40	43				173	.11
22	80	38	45				173	.11
23	79	40	46		.01		853	.57
24	77	41	48		.02		654	.44
25	59	47	27		.05		651	.43
26	60	37	53	2.51			80	.06
27	68	44	52	2.51			221	.15
28	66	42	50	2.51			733	.49
29	52	45	42	3.20	.65		475	.32
30	57	38	33	1.36	.05		487	.33
31	60	42	--	1.36			794	.53
Ave.	61.2	35.9	41.2					

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
6/1/67	65	40	--	4.71		.30	720	.48
2	69	39	--	4.71		.12	756	.50
3	71	39	44	4.71		.09	338	.22
4	68	43	36	4.34		.62	615	.41
5	69	50	--	2.24		.40	384	.26
6	65	44	53	2.68	.19	.19	723	.48
7	62	40	50	3.13	.01	.17	624	.42
8	61	40	55	4.72		.17	--	--
9	59	37	53	2.95		.22	655	.44
10	64	39	48	2.64	.04	.18	758	.50
11	65	41	50	2.64	.07	.49	758	.50
12	63	40	58	2.64		.14	758	.50
13	64	40	30	2.37	.15	.24	696	.46
14	56	42	55	3.54	.03	.14	899	.60
15	60	42	54	1.87	.16	.20	688	.46
16	64	46	56	2.63	.17	.23	717	.48
17	69	44	56	2.07	.16	.18	764	.51
18	74	43	53	2.07	.03	.18	849	.57
19	80	46	51	2.07		.18	873	.58
20	69	51	54	1.48		.11	911	.61
21	72	50	55	3.69	Trace	.15	661	.44
22	74	48	56	2.39	Trace	--	798	.53
23	58	43	42	2.62	.30	.45	659	.44
24	68	37	34	1.76	.32	.17	623	.42
25	73	44	55	1.76		.17	623	.42
26	75	45	50	1.76		.17	623	.42
27	77	50	56	2.89		.16	892	.59
28	72	51	53	3.30	.03	.20	884	.59
29	80	46	46	1.46		.15	768	.51
30	82	46	56	0.98		.01	966	.65
Ave.	68.3	43.5	50.3	2.76		0.21	726	.48

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
7/1/67	85	48	56	3/			884	.59
2	84	45	55			--	884	.59
3	84	48	--			--	884	.59
4	78	51	54			--	884	.59
5	83	43	52			--	884	.59
6	78	49	56			--	864	.57
7	76	48	34		.15	--	614	.41
8	78	47	55			--	654	.44
9	82	44	48		.10	--	654	.44
10	85	46	54			--	654	.44
11	82	50	50			.65?	838	.56
12	86	50	55			.14	759	.51
13	90	56	54			.29	944	.63
14	82	59	47			.38	642?	.43?
15	80	56	41		.15	.29	753	.50
16	81	51	55			.29	753	.50
17	75	56	51			.29	753	.50
18	80	47	55			.41	626	.42
19	83	49	54		.05	.28	786	.52
20	88	47	55			.32	720	.48
21	90	48	49			.32	786	.56
22	90	51	44			.24	821	.55
23	86	60	38			.24	821	.55
24	84	50	51			.24	821	.55
25	86	46	46		Trace	.48	434	.29
26	87	49	48			.23	664	.44
27	81	49	65			.50	1295?	.87?
28	87	42	--			.43	773	.52
29	89	47	41			.28	812	.54
30	81	58	46			.28	812	.54
31	83	56	58			.28	759	.51
Ave.	83.4	49.9	49.8			.33	782	.52

3/Daily wind velocity records missing, July 1 - August 13. Average wind velocity during this period 2.32 miles per hour.

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
8/1/67	84	51	56	3/		--	781	.52
2	84	51	55			.26	886	.59
3	85	49	47			.26	775	.52
4	88	50	57			.32	699	.46
5	87	53	53			.25	765	.51
6	82	50	57			.25	765	.51
7	82	58	56			.25	765	.51
8	82	44	53			.35	765	.51
9	84	48	49			.36	744	.50
10	86	49	49			.35	929	.62
11	87	51	50			.34	915	.61
12	85	52	50			.25	654	.44
13	84	49	53			.25	654	.44
14	83	44	47			.25	654	.44
15	85	48	55	1.94	Trace	.15	391	.26
16	88	48	49	2.14		.36	690	.46
17	86	47	52	2.24		.40	594	.40
18	85	49	48	2.45	.03	.31	385?	.26?
19	86	44	60	2.42		.27	595	.40
20	85	48	53	2.42		.27	595	.40
21	84	44	44	2.42	Trace	.27	595	.40
22	83	46	55	2.25		.30	381	.26
23	87	42	48	2.44		.38	558	.37
24	87	47	45	2.23		.39	555	.37
25	86	48	54	1.92		.31	656	.44
26	84	47	49	3.07		.47	718	.48
27	83	49	49	3.07		.47	718	.48
28	82	47	54	3.07		.47	718	.48
29	70	51	46	1.99		.30	757	.50
30	77	44	60	1.94		.21	218	.15
31	78	44	53	2.97		.23	501	.33
Ave.	83.8	48.1	51.8	2.41		.31	658	.44

3/Daily wind velocity records missing, July 1 - August 13. Average wind velocity during this period 2.32 miles per hour.

APPENDIX.--Climatic Measurements, Seedskadee Farm, Continued

Date	Air Temperature °F		Relative Humidity 0800, Percent	Wind Velocity Miles/hour	Precipitation (in.)	Evaporation (in.)	Total Solar Radiation	
	Max.	Min.					Langleys	Evaporation Equiv., in.
9/1/67	83	43	44	2.18	.03	.11	605	.41
2	84	46	54	2.38		.33	491	.33
3	86	44	54	2.38		.33	514	.34
4	84	47	38	2.38		.33	514	.34
5	84	48	47	2.15		.32	618	.41
6	78	52	54	2.81		.16	947	.63
7	80	44	57	2.95		--	496	.33
8	73	52	45	1.62		--	506	.34
9	76	51	56	2.86		.19	268	.18
10	77	45	52	2.86		.19	268	.18
11	70	44	44	2.86		.19	268	.18
12	50	32	57	5.18	.10	--	268	.18
13	59	30	56	5.18		--	268	.18
14	67	30	56	3.25		--	268	.18
15	69	35	55	2.08		.20	268	.18
16	65	42	56	3.85		.20	276	.19
17	66	37	47	3.85		.20	276	.19
18	60	36	--	2.06	.05	.20	276	.19
19	64	32	36	2.73	Trace	.10	93?	.06
20	74	32	54	1.33		.08	534	.36
21	80	39	56	1.23		.22	46	.03
22	77	38	54	1.90		.29	33	.02
23	78	42	48	1.90		.17	369	.25
24	80	43	52	1.90		.17	369	.25
25	76	43	56	1.54		.17	369	.25
26	67	44	52	2.50		.20	360	.24
27	69	34	52	0.86		.15	109	.07
28	80	38	56	1.22		.10	462	.31
29	80	37	54	--		.10	83	.06
30	66	46	55	--		--	--	--
Ave.	73.4	40.9	51.6	2.50		.20	353	.24