THE UNIVERSITY OF MANITOBA

EVALUATION OF POROUS DRIP IRRIGATION TUBING 'VIAFLO' FOR IRRIGATION OF ROW CROPS IN MANITOBA

by

Udeh Nwachukwu Charles

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

WINNIPEG, MANITOBA

February 1976

"EVALUATION OF POROUS DRIP IRRIGATION TUBING 'VIAFLO' FOR IRRIGATION OF ROW CROPS IN MANITOBA"

by

UDEH NWACHUKWU CHARLES

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

This study investigated the performance characteristics of Viaflo porous tubing for the irrigation of row crops. It involved preliminary laboratory testing and field experimentation at the Glenlea Research Station of the Faculty of Agriculture at the University of Manitoba.

The size of the plot was 110 m x 25 m, on a slope of 1.1 to 1.2 percent. The soil was predominantly clay with a very high phosphorous and potassium content. During the study, the crop grown was corn.

Four subplots - the surface-laid Viaflo system, the buried Viaflo system, the furrow irrigation system and the non-irrigated subplot--were established. Fertilizer was not applied on any of them. Irrigation and moisture measurement were continuous through August. A Troxler depth moisture gauge Model 1255 and a Troxler ratemeter Model 2651 were used in the moisture measurements.

Irrigation affected the moisture regime in the upper layer of the soil profile but did not significantly alter the moisture levels at the 60-cm soil depth and deeper.

The crop appeared to suffer no moisture stress. Highest crop yield and more uniform crop stands were obtained on the furrow-irrigated treatment. Yields on both surface and subsurface trickle irrigated subplots were equal. The relative yield percentages and water use efficiencies were higher for the trickle-irrigated systems. Soil erosion, weeds and non-uniform water application significantly affected reported yields in the trickle irrigation systems. In the surface subplots, some plants leaned.

In the field, drip-line discharge was high initially but stabilized

considerably with time. The buried Viaflo system applied water to the soil more efficiently than the surface-laid Viaflo system. There was no significant correlation between Viaflo laboratory discharge rates and field rates.

Filtration of the irrigation water for the trickle irrigation was inadequate. The surface-laid drip lines deteriorated considerably due to algal growth and ultraviolet degradation.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. F. Penkava, the project supervisor, for his encouragement, constant guidance and patience throughout this work.

The author also expresses his deep appreciation to Dr. G. E. Laliberte for his review, comments and suggestions on the thesis.

Appreciation is also extended to the other members of the Agricultural Engineering Department and summer students for their assistance.

Thanks are due to the Faculty of Graduate Studies of the University of Manitoba for providing the necessary funds.

Karol and Okay continue to pray.

For her excellent job of typing the manuscript, thanks are also extended to Mrs. Darlene Lowry.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE		PAGE

CHAPTER I

INTRODUCTION

Surface irrigation has been practised from time immemorial. Egypt claims to have had the world's oldest dam, built some 5000 years ago to store water for drinking and irrigation. Basin irrigation introduced in the Nile Valley around 3000 B.C. still plays an important role in Egyptian agriculture (19).

Quantitative and qualitative evaluation of surface irrigation methods indicate that they are water and labor intensive. Waterlogging and salinity problems often plague surface irrigation systems. Efficiencies are low even for well planned, properly designed, properly operated and adequately maintained irrigation schemes. Lower efficiencies are reported in the developing arid and semi-arid regions of the world. In these areas also, surface irrigation methods are often accountable for malaria and bilharzia disease hazards (49).

Over the years, no basic change has occurred in this method. Only recently some degree of sophistication and limited automation has been introduced (18, 21). But the problem of water economy still remains unsolved.

Incidentally, on the Canadian prairies, because of the soil, topography, wind and the short growing season, this method, in spite of its several disadvantages, is highly recommended by some irrigation experts.

With the development of pumps, lightweight noncorrosive metals and plastics, overhead irrigation i.e. sprinkler irrigation, was introduced in the farms. It has now gained some popularity in areas where the surface methods were considered not feasible. Sprinkler irrigation systems, if properly designed in accordance with the soil-water properties, cropping pattern and wind, are expected to minimize most loss factors (deep percolation, waterlogging) found in the surface methods. Efficiencies as high as 80 percent have been reported.

Recently sprinkler sophistication and automation have considerably increased interest in this irrigation method. But the system's energy demand has increased significantly also. In the developed rich nations, the general trend in the irrigation field to the most sophisticated mechanical-move sprinkler systems with their relative high power demand in this day of world-wide energy concern, is considered irrational by some workers (25).

Lately, trickle irrigation has experience a tremendous growth in the development of irrigation water application techniques (10). This innovation has become a new functional tool to boost crop production particularly in the tropical, subtropical and arid regions of the world (46). Israel has successfully employed this tool to greatly improve her desert agriculture. Significant water savings have also been reported.

Although trickle irrigation originated in the arid areas, researchers have confirmed that most of its advantages are possible in the humid regions as well (8).

In Canada, trickle irrigation is yet in its infancy. But it is possible that it may prove to be a useful tool in minimizing farm energy demand and increasing crop production.

However, the realisation of trickle irrigation potential calls for research on this method. Trickle irrigation has introduced new irrigation concepts probably different from the conventional ones. Their deeper understanding and investigation are essential before reliable design criteria can be recommended. Also, there are many trickle irrigation system components already on sale in North American markets. But due to the frequent discrepancies of their operational characteristics in the field with much of the sales literature, it becomes necessary to adequately test them before suggesting reliable field design criteria (38).

In the United States, Israel and Australia particularly, much work has already been done and reported in this direction. Similar studies are still underway in several Canadian research institutions.

The objective of this study is the evaluation of the high-frequency porous tubing 'Viaflo', for use in irrigation of row crops in Manitoba. Factors to be considered shall include the following:

i) laboratory and field performance characteristics of the porous tubing,

ii) crop response to surface and subsurface trickle irrigation as compared to furrow irrigation, and

iii) water quantities applied for each irrigation method.

CHAPTER II

REVIEW OF LITERATURE

2.1 Trickle Irrigation Definitions and Concepts

Researchers have defined trickle irrigation in various ways. Chapin (6) described it as an irrigation method which provides water uniformly and slowly directly to the base of the plant. While furrow irrigation floods the space between crop rows, drip irrigation waters only next to the plants in the rows. He suggested also that a good drip irrigation system for row crops should provide uniform water delivery over long length, have simple and fast installation, have a low per-acre cost, be available in long rolls adaptable to mechanical installation, have water delivery rates best suited to the crop and existing soil conditions, have a large enough water outlet to minimize emitter clogging, and be adaptable to sloping land.

Spiess (40) defined drip irrigation as a method which involves the daily maintenance of an adequate section of the plant root zone at a moisture level close to the field capacity for the duration of the growing and productive season.

Kenworthy (23) reported that, with drip irrigation the best use of available water resources and best plant performance may be realised through preventing moisture stress (rather than correcting it) for only a portion of the root system. Therefore, a trickle irrigation system must provide daily, to 25 percent of the root system, enough water to replenish anv soil moisture deficit.

Phene (34) demonstrated that, in humid regions, a high-frequency controlled irrigation (trickle) can alleviate short drought periods without risking erratic rainfalls which results in excessive soil water contents, and which may cause low oxygen diffusion rate and losses of nutrients by erosion, runoff and leaching.

The basic concept of trickle irrigation generally, is that the soil needs water only in the area where the plant roots are situated and not the entire field.

2.1.1 Historical Background of Trickle Irrigation

Trickle irrigation started just like the name implies -- slowly (44). The term 'trickle' originated in England, 'drip' in Israel and 'daily flow' in Australia (23).

As early as 1899, the Germans conducted experiments on subsurface irrigation with sewage water (9). However, 40 years ago, they developed a trickle irrigation system to supply water to the orchards (45).

In 1918, a bulletin on "Irrigation by Means of Underground Porous Pipe" was published by the Colorado State Agriculture and Mechanical College (9).

In 1934, a line source porous canvas hose was used by Robey (13).

Shortly after World War II rubber tubing with various emitters was commerically produced in Europe for greenhouse irrigation (13).

In Israel, to cope with the nation's limited water resources and increase crop production under her desert agriculture, field investigations of trickle irrigation began in 1959, and in 1962 Symcha Blass developed a drip irrigation system in Israel (24).

Chapin (1973) claims that one of the first row crop installations in the United States was made by County Agent Norman Smith in 1963, using micro-tubes on cantaloupes, and in 1964 using dew-hose beneath a plastic mulch (6).

In 1965, trickle irrigation study began in Australia (51).

About 1970, this irrigation concept reached San Diego, California, after Don Gustalfson, Farm Adviser on sabbatical leave from the University of California, was exposed to the idea in Israel (14).

Only a few years ago, this concept was introduced in Canada (7).

2.1.2 Current Status of Trickle Irrigation

Current interest in trickle irrigation in other countries is probably attributed to Israel's successful experiences in the adverse Arava desert conditions (9).

Initial field trials resulted in surprisingly high crop yields particularly under the adverse arid conditions. This led to a rather rapid acceptance of trickle irrigation by growers; by passing the normal research and development procedures (13).

By 1970, over nine different firms in the United States alone, were producing and helping to install trickle components (27). Altogether, there were over 65 firms producing trickle components in the world (32).

Two international conferences on drip irrigation have been held so far; the first in Israel in 1967 dealt primarily on Israel's drip irrigation experiences, while the second conference was in San Diego in 1974. The San Diego conference was a technology transfer based on different experiences and sharing ideas, findings and plans (10).

Statistics indicate that Israel has over 6070 ha (15,000 ac.), Australia over 4040 ha (10,000 ac.), Hawaii over 5059 ha (12,500 ac.) and South Africa over 3480 ha (8,600 ac.), under trickle irrigation.

The area under trickle irrigation in the United States has gone from 40 ha, five years ago to 29063 ha presently (50). In the United States, interest in trickle irrigation is greatest in the Western states:

Nebraska, California, Texas, Alabama, Arizona and Utah. Only five years after the trickle irrigation concept had reached California, over 20234 ha (50,000 ac) have been trickle-irrigated (14).

In Canada, at Brooks, Alberta, a co-operative test project is being conducted by the Alberta Horticultural Reseach Centre and the Alberta Department of Agriculture (7). Some orchards, vineyards and row crops are now trickle-irrigated in British Columbia (43).

Intensive studies on drip irrigation are currently underway in many research institutions and universities in the United States, Israel, Australia, Canada and in other countries. Table 2.1 shows the statistics of a world-wide trickle irrigation survey.

2.2 Trickle Irrigation System Components

Usually a drip irrigation system consists of the following components;

i) the head unit

ii) the main line, and

iii) the drip lines with emitters.

2.2.1 The Head Unit

The head unit may consist of a water supply source, pump, filters, pressure gauges, pressure regulators, water meter, and fertilizer tank. If water is of low quality (high total solids), a settling or sediment basin, and intake syphon may be additional components of the system's head unit. A head unit performs three main functions;

i) supply of good quality water,

ii) pressure regulation, and

iii) fertilizer injection, if fertilizers are applied through the system.

Table 2.1 World-wide Drip Irrigation Survey[1]

State or Country	Present Hectarage	Present Acreage
United States		
Alabama	3	7
Arizona	2,023	5,000
California	16,188	40,000
Colorado	2	5
Delaware	2	5
Florida	2,428	6,000
Georgia	33	82
Hawaii	5,058	12,500
Indiana	16	40
Kentucky	2	5
Louisana	8	20
Michigan	1,214	3,000
Missouri	24	60
Nebraska	1	2
New Mexico	161	400
New York	61	150
North Carolina	12	30
Ohio	2	5
Oregon	132	325
Pennsylvania	22	55
South Carolina	5	12
Texas	1,214	3,000
Utah	40	100
Washington	404	1,000
United States total	29,063+	71,816+
Other countries		
Australia	10,117	25,000
Canada	202	500
Central America	283	700
Cyprus	160	400
Israel	6,070	15,000
Mexico	6,475	16,000
New Zealand	809	2,000
South Africa	3,480	8,600
Total	28,814	71,200

[1]Extract from the Proceedings of the Second International Drip Irrigation Congress. San Diego, California, July 1974.

2.2.1.1 Filtration of irrigation water

The most crucial factor in drip irrigation is the water quality. Water quality is dependent, to a considerable extent, on the method and hardware necessary to provide for efficient filtration of the irrigation water.

No water standards have yet been established for the drip irrigation water quality. Poor water quality has significant effects on trickle irrigation systems' performance , due to the clogging of emitters.

Emitter blockages are caused by particulate matter in the irrigation water, rust and leaves. The chemical composition of irrigation water and microbial activities may also cause emitter blockages.

In most drip systems, filtration has proven efficient in handling suspended solids. But plugging due to algal growth on emitters is normally controlled with chlorine, permanganate and copper sulphate.

The filtration requirements and filter types depend on the water quality, emitter types and the trickle systems' operating pressures.

Trickle systems with high operating pressures may have reasonably clog-free emitters. But low pressure systems require more careful filter selection and efficient filtration of irrigation water.

Some emitter types (spot emitter) have built-in devices to minimize clogging.

A 150-mesh in-line strainer is an adequate filtration assembly for drinking water sources (29). But where suspended solids are extremely high, a sediment basin followed by filtration is normally recommended. A back-flushing replaceable sand filter followed by a finishing 25-micron filter is generally advisable for water supplies with high solid contents.

2.2.1.2 Pressure regulation need

Emitter discharge and uniformity of water distribution are considerably affected by emitter clogging and fluctuating operating pressures. Due to low operating pressures of most emitters, a small variation of topography influences operating pressures considerably. If irrigation water is taken from a municipal supply line, pressure fluctuations are very frequent. To ensure optimal and well balanced pressures, pressure regulation is essential in most cases.

Viaflo porous tubing requires the installation of a standpipe of at least the same diameter as the 'header' pipe, at the head unit. The standpipe should be 1.01 cm long for each g-cm^{-2} of design operating pressure. If, for some reason, the system's pressure exceeds optimum pressure, water flows out of the standpipe. But for rapid-rise and erratic pressure fluctuations, the standpipe response may probably be too slow to prevent damage to the drip lines.

A wooden stand of predetermined height and a tank with a float valve to control the water level, mounted on top of the stand, may be a more suitable pressure control arrangement.

The installation of this pressure control set-up should be normally at the highest elevation on the farm (where practicable).

Pressure regulation may also be achieved by using pressure relief valves and regulators.

2.2.1.3 Fertilizer injector

This unit is optional depending on whether or not fertilizer is to be applied through the system.

The application of plant nutrients through trickle irrigation systems is the most convenient and efficient method of applying fertilizer.

Nutrients such as nitrogen, which are water-soluble and mobile in the soil, are easily applied through trickle irrigation systems. However, for some other nutrients such as phosphorous, it is difficult to achieve proper placement with trickle irrigation systems, due to precipitation and chemical reaction with irrigation water. Water-soluble forms of N, P, K, Ca and Mg, for example, glycerophosphate or monosodium phosphate, applied through the system have proven practical (36). But monosodium phosphate applied with well water from basaltic formations has resulted in precipitation.

2.2.2 The Main Line

The main line brings water from the supply source to the farm. The main line pipe selection (type, size) depends on the calculated gross irrigation requirement and follows the normal hydraulic design processes.

2.2.3 Emitters and the High Frequency Porous Tubing, 'Viaflo'

Researchers, Busch and Kneebone, Zetzsche and Newman et al. used perforated plastic-pipe emitters (5, 22). Many firms are now producing various types of emitters. Some of them are: Drip Eze, Arjac Bi-wall, Chapin Double Wall, Salco, Rinko, Spears, Uniflow, Netafim, Spot, Viaflo porous tubing etc.

The Viaflo is a porous plastic tubing made from a patented polyethylene sheet (2). With the application of a few kg-cm^{-2} water pressure, the tubing inflates and water oozes out of the numerous four-micron size pores in the body wall. Pores make up 50 percent of the total wall area. Viaflo is a product of the DuPont Company. It is lightweight, compact and can be mechanically installed underground. DuPont claims that the properties of Viaflo include extreme strength, tear resistance and chemical inertness.

It is, however, subject to ultraviolet degradation. According to the DuPont Company the optimal operating pressure range is 0.24 to 0.28 $kg\text{-}cm^{-2}$. At this pressure the rated discharge is 1253 ℓ per day per 100 m of tubing length. (0.7 gpm per 1000 ft). Herbicide, insecticide and fertilizer injection through the tubing is not yet advised.

2.3 Research on Trickle Irrigation

2.3.1 Research on Crop Response Due to Trickle Irrigation

Superior crop performance and considerable water savings due to trickle irrigation have been reported by many researchers (4, 17, 34, 42, 48). But trickle irrigation is far from being a universal panacea; responses in some conditions and crops may be poor. Trickle irrigation in citrus orchards on sandy soil so far have failed (31). The highest yield of sweet corn 'Cultivar Merit' was obtained with sprinkler irrigation (11). In some situations, drip irrigation did not significantly increase yield over the furrow method. Eliezer (1973) and co-workers in Israel reported no significant difference in yield for citrus under trickle irrigation and sprinkler irrigation (12).

Trickle irrigation, therefore does not necessarily increase yields when compared with well managed alternative systems particularly in areas of moderate climate having an adequate supply of water of reasonable quality.

There is also evidence of bias in research reports due to the fact that people most active and enthusiastic in developing the method are also doing the accompanying research (13).

2.3.2 Drip Irrigation With Saline Water

Drip irrigation permits the use of relatively saline water.

Goldberg (1971) successfully used a 3000 μmhos/cm water to irrigate tomatoes in Israel. Afforestation with saline water, drip irrigation was also successful (37). Bernstein and Francois have used brackish water to produce crop yields very comparable to yields obtained with good quality water (3).

2.3.3 Frequent Irrigation With Trickle

Waldeigh and co-workers (13) showed that matric and osmotic potentials are additive in their effect on plant growth. Frequent water application assures that the soil salinity will not appreciably exceed the salinity of the irrigation water provided leaching is adequate.

On coarse sands and soils of high porosity, daily or even more frequent irrigation to retain sufficient moisture in the root zone, may be necessary. Black (1969) and Smart (1970) regard daily irrigation as preferable even on heavier soils, as long as trickle irrigation maintains a water application rate matching the soil infiltration rate. Problems associated with surface sealing and runoff due to high application rates, are eliminated (20).

It has been demonstrated however, that frequent irrigation may not always increase yields on fine-textured soils of high water-holding capacity.

2.3.4 Automation of Drip Irrigation Systems

Researchers (26, 29, 33, 35) have shown that automation is easily possible with trickle irrigation. In Texas, tomatoes in greenhouses have been successfully irrigated automatically with the use of a switching tensiometer. Soil matric potential sensors have also been used.

Automation provides better opportunities for precise timing and dosage treatments according to specific periodical crop needs.

2.3.5 Some Other Advantages of Trickle Irrigation

Some other advantages of trickle irrigation are as follows:

i) simplified fertilizer application and disease control,

ii) weed control; the non-irrigated interrow spaces normally remain relatively dry,

iii) no wind effects on water distribution,

iv) deep percolation, surface runoff and evaporation losses are practically eliminated. The non-irrigated interrow spaces serve as a sink for rain water, and

v) low pressure and low discharge characteristics of drip systems permit an economical pipe and pump selection. With low discharges, the soil infiltration for soils of low water intake, is greatly improved.

CHAPTER III

NEW IRRIGATION CONCEPTS

3.1 Crop Spacing and Soil Fertility

A small flow of water applied to the base of a plant may wet a truncated ellipse of soil just below the plant. The plant thus develops a bunched-up root system similar to potted plants (46).

A water-fertilizer mix applied through a trickle of water to a confined root zone would be beneficial from the standpoint of soil fertility, fertilization and crop spacing. It is thus possible to plan to replace nutrient elements which are removed by the crops.

3.2 Crop Rooting Pattern Under Trickle Irrigation

Goldberg and co-workers (17) and Bernstein (3) found that irrigation tends to cause a high concentration of roots near the soil surface and to restrict the vertical root penetration. Restricted rooting volume, however, may be accompanied by a proportional root density increase. In the conventional methods of irrigation, roots from adjacent crop rows overlap in their search for water and nutrients. But a weak fertilizer solution injected into the irrigation water and applied through a trickle system would help to balance the nutrient uptake capacity of the bunched-up root system.

In humid areas, the rooting system was not restricted to the soil volume wetted by emitters; the roots were more proliferous (8).

In trickle-irrigated peach trees, the highest live root concentration was in the zone of readily available water and of adequate aeration. Poor aeration directly beneath drippers was observed to inhibit root development (47).

3.3 Modified Leaching Program for Trickle-irrigated Crops

Researchers (15, 17, 39) found that an advancing wetting front which carried salt to the periphery of the moisture profile, occurred with trickle irrigation. Such peripheral salt accumulation might have far-reaching effects on crop performance. A light rain might wash the salt into the active root zone where it would inhibit growth.

This phenomenon introduces a new soil reclamation procedure of spot leaching rather than the leaching of an entire area as normally practised.

3.4 Basic Functions of the Soil

Since drip irrigation replenishes the water deficit daily, or at very frequent intervals, the soil has ceased to be a significant factor for water storage between irrigations. The soil's basic function becomes anchorage (17). Even poor, coarse, arid soils fulfill this function. This explains why trickle irrigation normally has its best advantages, at least relatively, under conditions which are marginal for other methods.

3.5 Tensiometer Use in Irrigation Programming

On drip irrigation the soil moisture stress should never exceed 75 centibars. In fact, a desireable limit is 50 centibars. Within this limited available moisture range, tensiometers can operate properly, continuously and reliably as soil moisture detectors (16).

3.6 'Potential Transpiration' Concept

In conventional irrigation methods, deep percolation losses are often considerable. But with trickle irrigation, water application to a confined soil volume at the root zone can be made to match plant water transpiration losses. Transpiration evaluation is thus more accurate with the trickle irrigation method than with the conventional method.

Since trickle irrigation creates a potential moisture availability within the root zone with little or no evaporation from the soil surface, the evaporation element in potential evapotranspiration is almost eliminated. Some workers (1, 16) have proposed 60 percent of pan evaporation for the estimation of potential evapotranspiration for trickle-irrigated tree crops. For design purposes, 70 percent of pan evaporation was considered to be necessary (16).

The rationale for this proposal was based on the following considerations:

- low water application rates with trickle irrigation,
- optimal moisture stress range of 30 to 50 centibars,
- visible moisture surface always hidden under foliage or any other cover; and
- wetted surface area under trickle irrigation relatively small compared to the entire cropped area.

In spite of the diurnal variation and variations associated with crop development and weather, researchers have proposed 0.75 of pan evaporation as a close estimation of potential evapotranspiration (23).

Finally, trickle irrigation may necessitate general modifications in established practises of seed bed preparation, planting, weed control, levels and timing of fertilizer application and harvesting.

CHAPTER IV

EXPERIMENTAL METHODS AND INSTRUMENTATION

4.1 General

A study to determine the suitability of the high-frequency porous tubing Viaflo for the irrigation of row crops in Manitoba began in the winter of 1974 and continued until the first killing frost in September, 1975. The porous tubing Viaflo is a product of the DuPont Company and has been described in the literature.

The study involved preliminary laboratory testing and a field investigation on the clay soils of the University of Manitoba's Glenlea Research Station, about 20 km south of the University campus.

4.2 The Laboratory Experimental Apparatus

A control valve and a 25-micron filter were connected to a manometer-equipped reservoir located on a raised platform (Fig. 4.1). From the filter, plastic tubing led to a container equipped with a float valve maintaining constant water levels in the container. The container itself was suspended on an electric hoist and could be moved up and down in order to provide the required pressure for the tested sample of the Viaflo tubing (Fig. 4.2). A 'feeder' rubber tubing connected the container to the tested sample of Viaflo (Fig. 4.3).

4.2.1 Drip-line Discharge Measurements

With the control valve closed, the reservoir was filled with water to a level easily read off from the manometer attached to the reservoir. The container with the float valve was moved to a predetermined operating head using the electric hoist. A test sample of Viaflo,

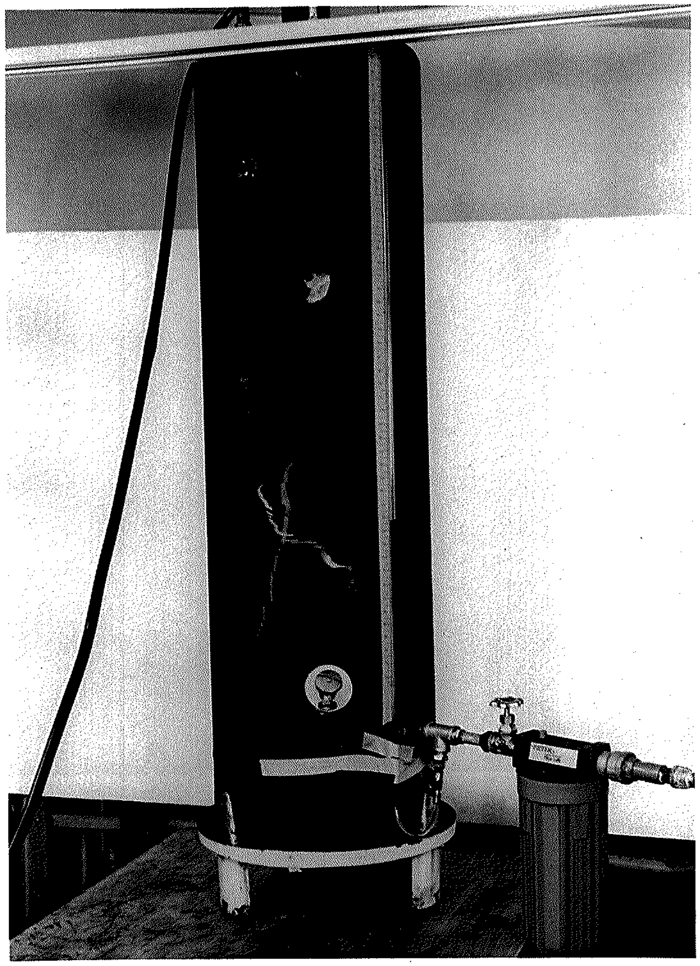


Fig. 4.1 A control valve and 25-micron filter connected to a reservoir

Fig. 4.3 Plastic container with a float valve connected to the test sample

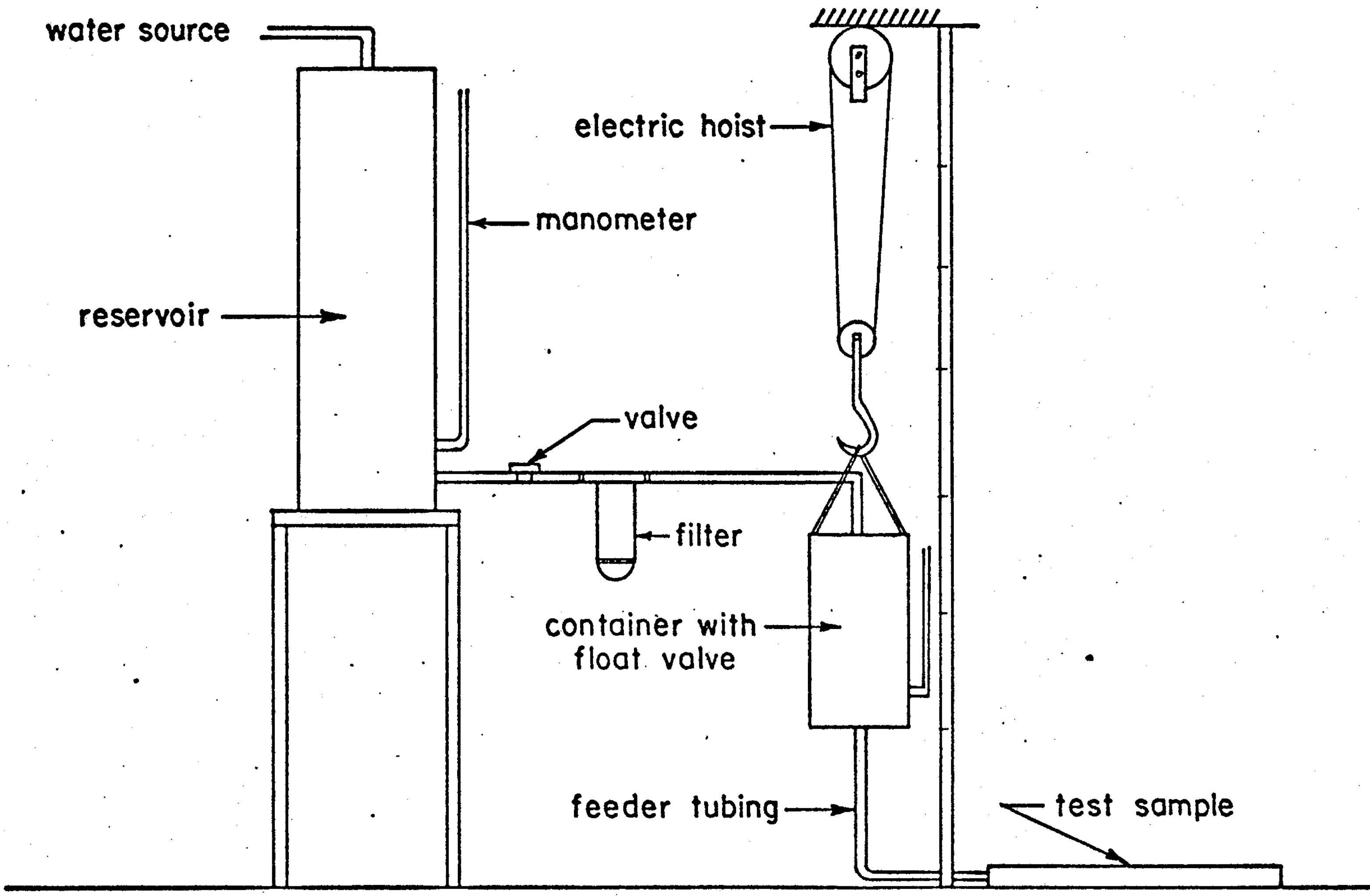


Fig. 4.2 Laboratory experimental apparatus

3 m long, was connected to the feeder tubing. As soon as the valve was open, water dripped from the test sample. The reservoir water levels, which indicated the "consumption" of water, were recorded every half hour for six hours. The drip-line discharge was evaluated from the water level changes.

The selected operating heads were 2, 2.5, 3, 3.5, 4, 4.5, and 4.85 m. For each operating head, three different equal-length (3 m) drip-tube samples were tested.

Two other samples were each connected and left dripping for two days to reach equilibrium conditions, before discharge measurements were taken. A 24-h average discharge for each operating head, was recorded for each test sample.

4.3 Description of the Field Plot Layout

A plot 110 m x 25 m in size, on an average slope of 1.1 percent, and close to a dug out was made available for the field trials. Twenty six rows spaced one meter apart were planted to corn on May 20, 1975. Five crop rows formed a subplot for each of the four considered treatments: surface-laid drip lines, buried drip lines, furrow irrigation and a non-irrigated subplot. A two-row buffer zone separated the subplots from each other (Fig. 4.4). Except for the non-irrigated treatment, each subplot has three moisture monitoring stations. At each station, five 1.37-m (4.5-ft) aluminium access tubes were installed to an average depth of 102 cm, spaced 50 cm and in a row (Fig. 4.5). An irrometer (tensiometer) 3 m away from each station, monitored the moisture stress at the 30-cm depth between two crop rows.

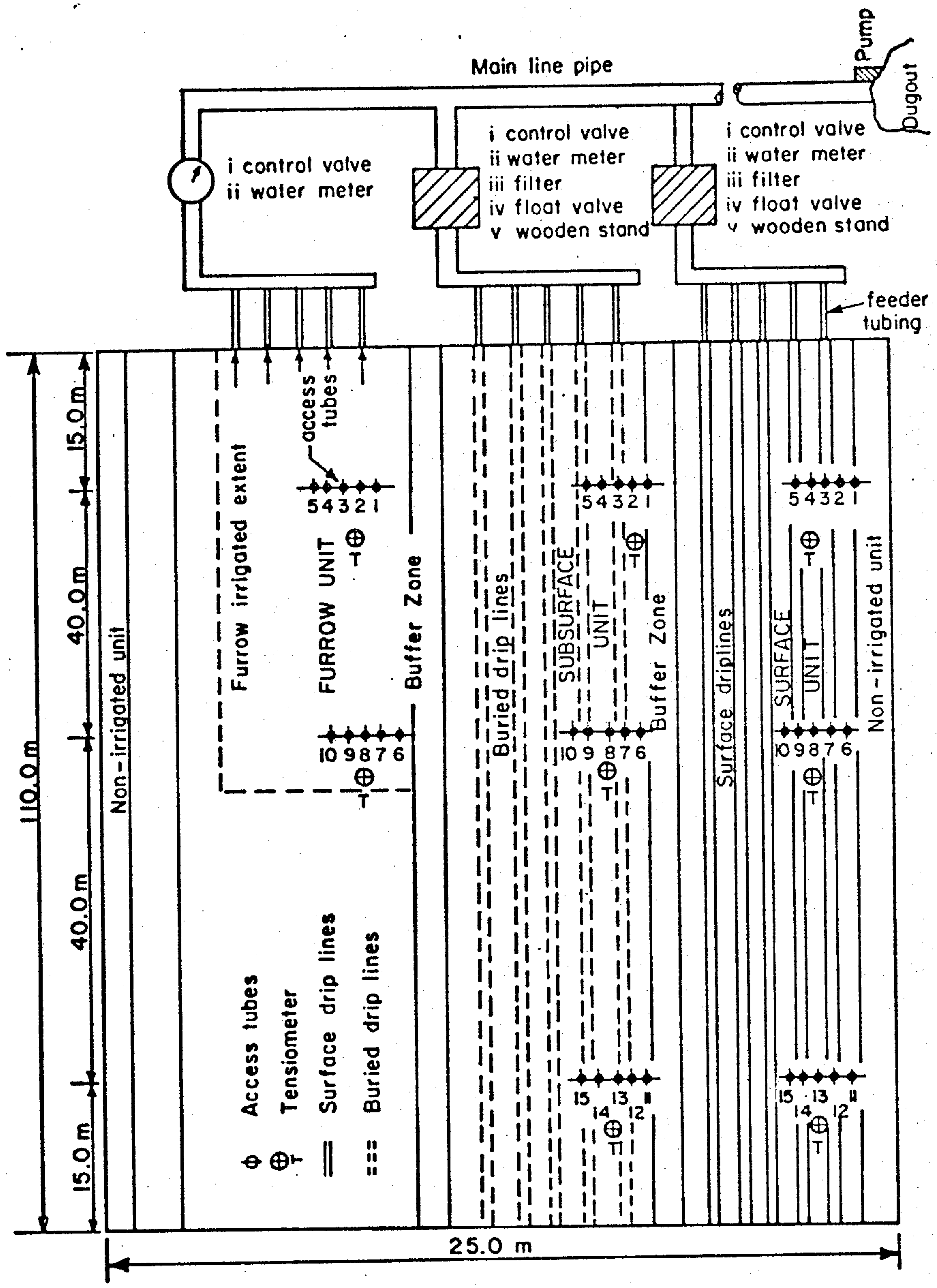


Fig. 4.4 Schematic plot layout for testing Viaflo drip lines

Fig. 4.5 Installation of access tubes at a moisture monitoring station

Fig. 4.6 Drip line along a crop row

4.3.1 Installation of the Access Tubes and Drip Lines

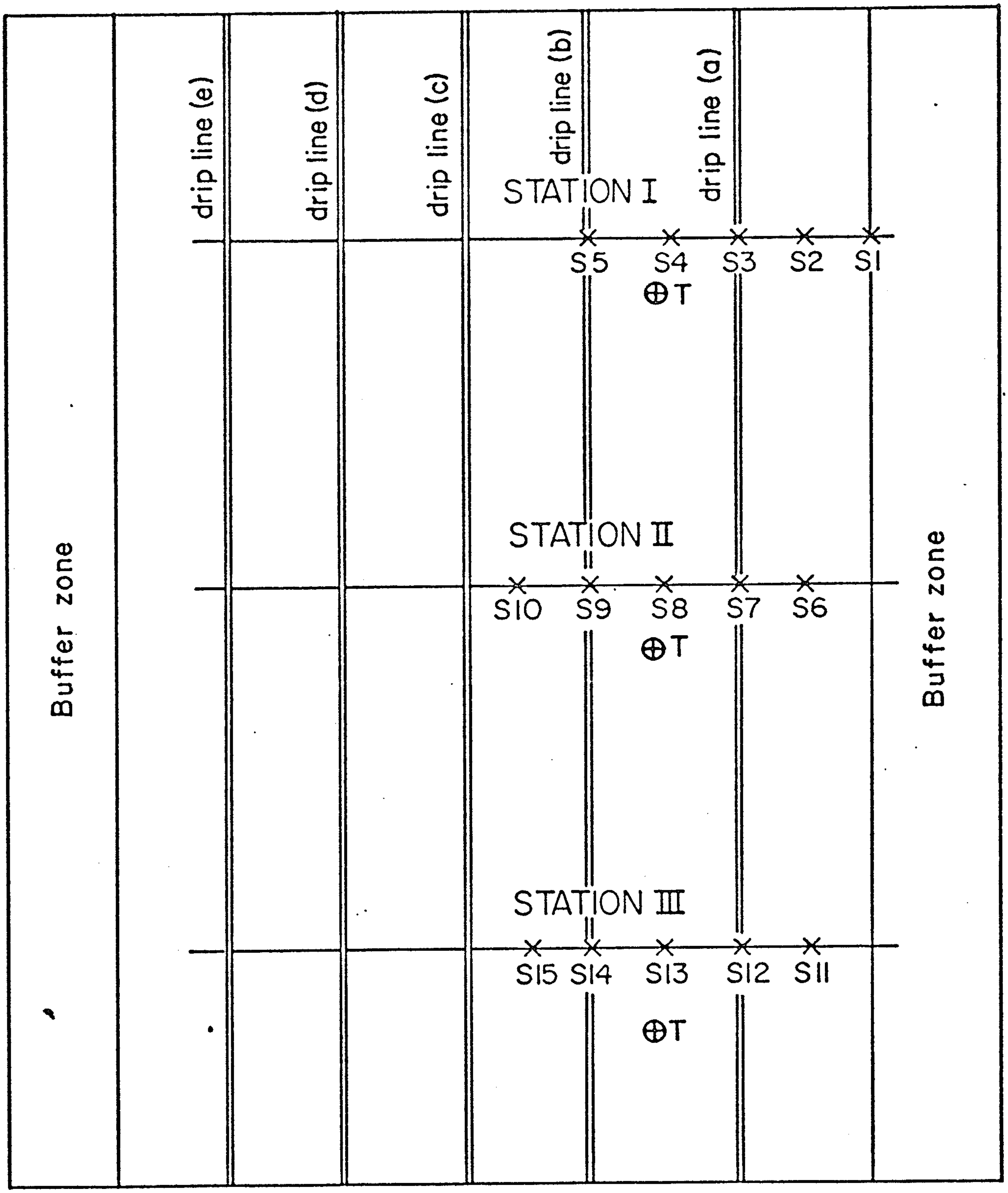
In the subplot with the surface-laid drip lines (for convenience herein called the surface subplot) and in the subplot with the buried drip lines (the subsurface subplot) the lines were laid at a horizontal distance, 15 cm from the row crops (Fig. 4.6). In the subsurface subplot, the drip lines were buried 10 cm deep.

In the surface subplot, access tubes S1, S3, S5 in station I, S7, S9 in station II and S12, and S14 in station III, were each installed between the drip line and a crop row. Tubes S2, S4 in station I, S6, S8, S10 in station II and S11, S13, S15 in station III, were each installed midway between two crop rows. Tube S1 was close to the non-irrigated row in the buffer zone. Tubes S3, S7, S12 were along the same drip line (a), while tubes S5, S9, and S14 were along another drip line (b) (Fig. 4.7).

Similarly, in the subsurface subplot, tubes B1, B3, B5 in station I, B7, B9 in station II and B12 and B14 in station III were each installed between a crop row and a drip line. Tubes B2, B4 in station I, B6, B8 and B10 in station II, and B11, B13, B15 in station III were each installed midway between two crop rows. Tube B1 was close to a non-irrigated row in the buffer zone. Tubes B3, B7, and B12 were along the same buried drip line (a), B5, B9 and B14 were along another buried drip line (b) (fig. 4.8).

In the furrow subplot, tubes F1, F3 and F5 in station I, F7 and F9 in station II, were each installed close to a crop row. Tubes F2, and F4 in station I and F6, F8, F10 in station II, were installed on the furrows. Tube F6 was,however, in the buffer zone.

The installation of the drip lines was done manually.



× = Access tubes
⊕T = Tensiometer

Fig. 4.7 Schematic diagram of the surface-irrigated subplot.

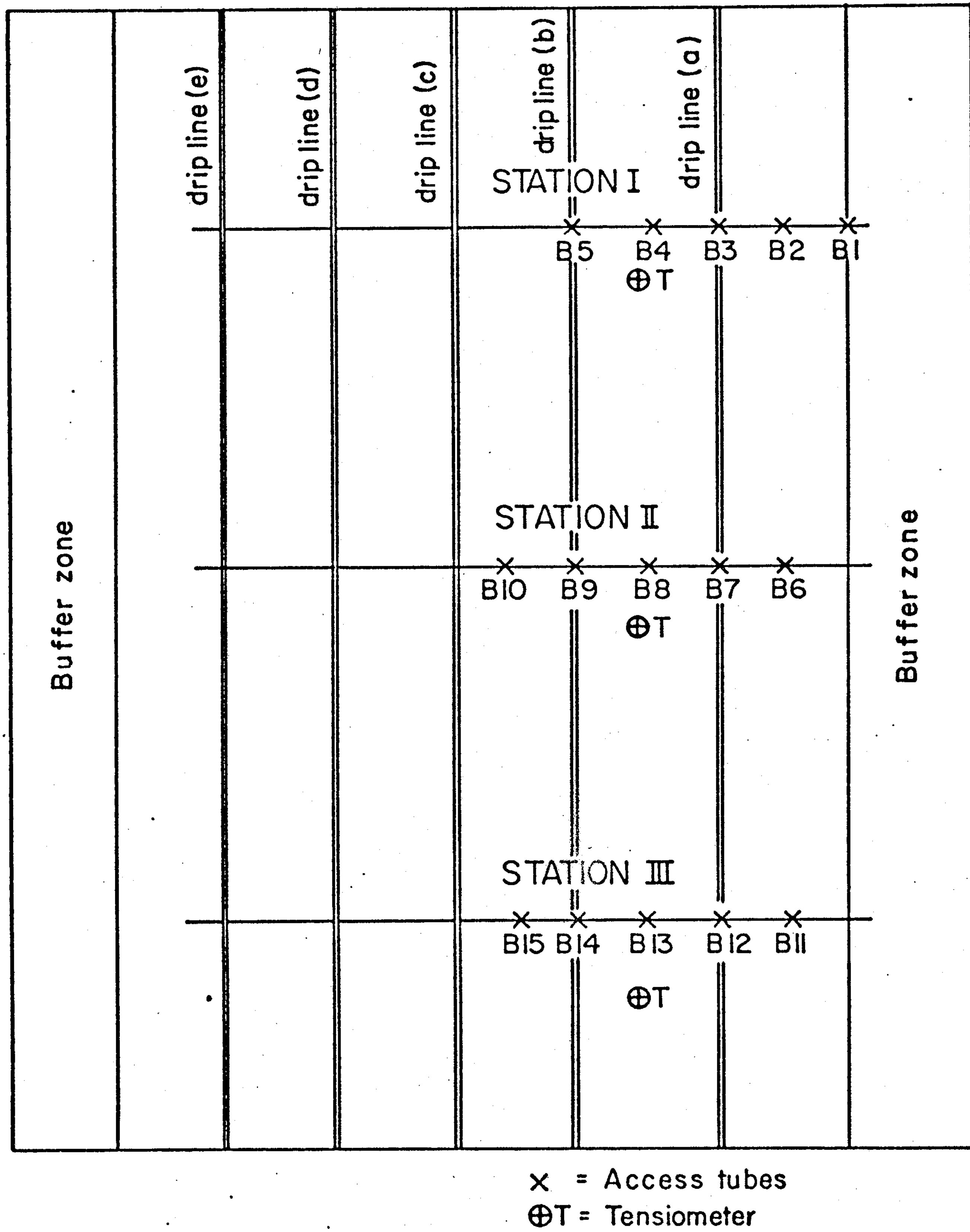


Fig. 4.8 Schematic diagram of the subsurface irrigated subplot.

4.3.2 Irrigation Water Supply

The irrigation water supply was obtained from a dugout which was located close to the experimental site. A pump installed near the dugout delivered water along a 2.5-cm diameter pvc main line pipe to the field (Fig. 4.9).

Upfield from both the surface and subsurface trickle irrigation subplots, two similar units designed to meter and to filter irrigation water and also to maintain a 330-cm constant operating head, were installed (Fig. 4.10).

Each unit consisted of a high wooden stand with a float-valve-equipped container mounted in a elevated position. A water meter and a 25-micron filter were connected with a 2.5-cm diameter plastic pipe and then mounted on a wooden platform. The platform was fixed near the base of the wooden stand. A length of 1.3-cm diameter plastic tubing connected the meter-filter unit to the float valve (Fig. 4.11).

From the main line, water passed first through the meter-filter unit and through the float valve into the container. The container was connected to the drip lines laid along the crop rows in each trickle irrigated subplot through five lengths of 'feeder' rubber tubing.

The furrow-irrigated subplot received metered but unfiltered water through five plastic pipes connected to the main line. The pipes were laid along the furrows (Fig. 4.12).

4.4 Measurement and Sampling Techniques

4.4.1 Soil Sampling and Analyses

Near each of the nine moisture monitoring stations, three soil samples at 0 to 15-cm , 15-cm to 30-cm, 30-cm to 60-cm depths, were

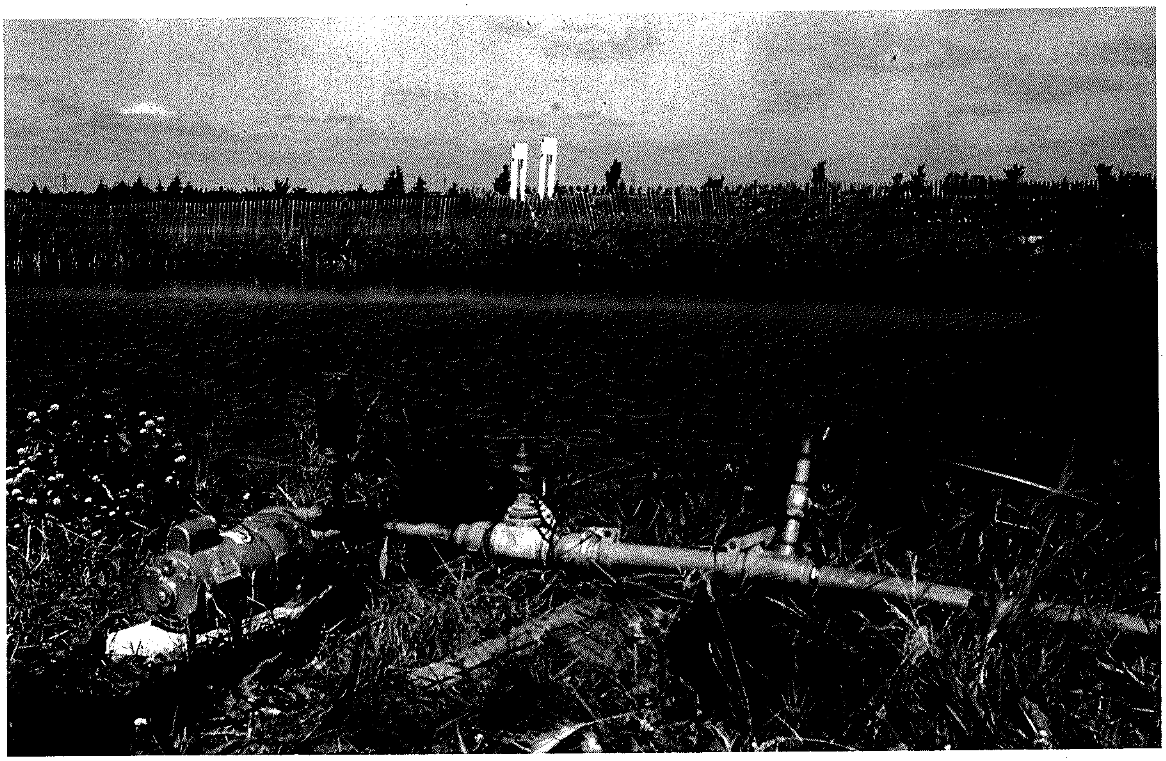


Fig. 4.9 Pump installation near a dugout

Fig. 4.10 Two similar constant-head water meters and filter assemblies for surface-laid and buried trickle irrigation system

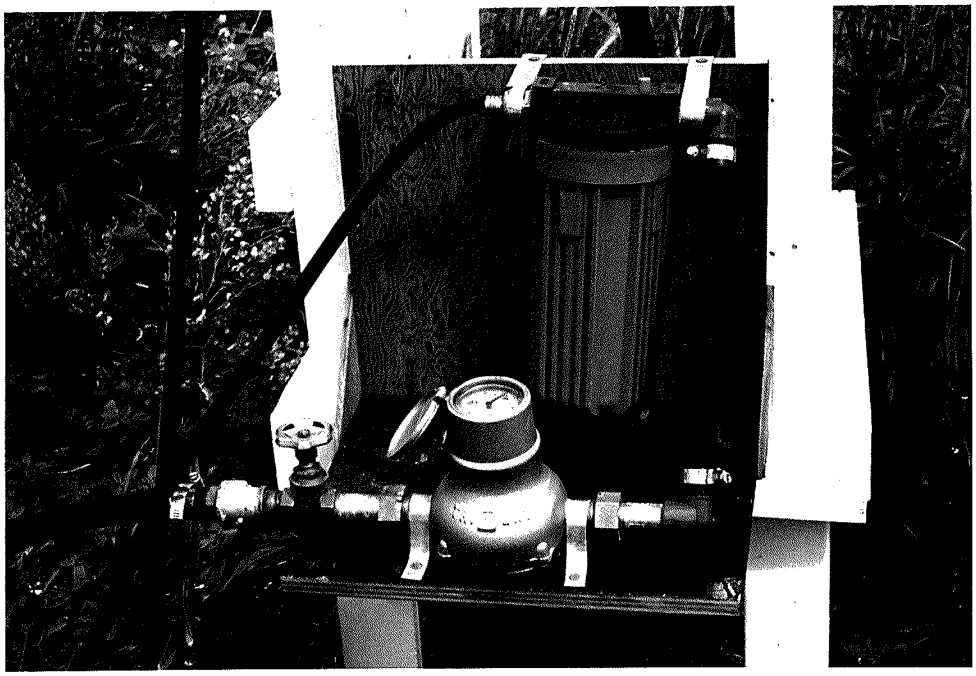


Fig. 4.11 A water meter and filter unit

Fig. 4.12 Furrow irrigation subplot

collected--27 samples in all. The mechanical analyses were done in the soil and water laboratory of the Department of Agricultural Engineering by the writer. The hydrometer method was used. Samples were also sent to the Soil Testing Laboratory of the Manitoba Department of Agriculture for the determination of the N, P, K, and Ca contents, the pH and the electrical conductivity levels.

4.4.2 Irrigation Water Analysis

Three samples were collected from each of the dugout, the furrow line, and the surface and subsurface lines after the water had passed through the filters. The samples were then sent for the chemical and physical analyses.

4.4.3 Weed Control

The chemical Banvel 3 used to control the weeds, proved ineffective in destroying a dense wheat growth over all the experimental plot but the furrow subplot. Wheat seeds from the previous cropping germinated in the other subplots but were buried deep during the cutting of the furrows.

4.4.4 Fertilizer Application

Throughout the study, no fertilizer was applied to any of the treatments. The introduction of fertilizer in the irrigation water before the results of the water analysis, was considered risky. It was feared that a chemical reaction of the fertilizer and the irrigation water might result in a precipitation and plugging of the drip lines.

Potassium is not needed when corn is grown on the loam to clay-loam soils of this region.

4.4.5 Irrigation Scheduling and Soil Moisture Measurements

Initially, both the surface and subsurface treatments were irrigated daily for three hours. After two (five-day) weeks, it was found that a significant moisture depletion occurred at the 0 to 15-cm depth. Only about 40 ℓ of water was supplied to each treatment in three hours. This was equivalent to 2.4 ℓ in three hours per 100 m of crop row length and only about 57.6 ℓ per day per 100 m of crop row.

Due to this low discharge and increased crop development, irrigation was continuous thereafter except when it had rained.

Rainfalls exceeding 2.5 mm were considered effective and thus equivalent to an irrigation.

Moisture measurements were taken daily at 10.00 h and 13:30 h, five days a week, through August. Pollination, considered a critical stage in terms of moisture availability for corn production, occurred in August.

In the furrow-irrigated subplot, readings were taken 24 hours after each irrigation. There were two such irrigation periods, occurring one month apart.

The Troxler depth moisture gauge Model 1255 was used in the measurement of moisture content. The Troxler output was evaluated with the Troxler ratemeter Model 2651 (Fig. 4.14). On each access tube, readings were taken at the 15-cm, 30-cm, 60-cm and 98-cm depths. Tensiometer readings were also recorded during every moisture measurement.

Fig. 4.13 Selecting depths for moisture determination

Fig. 4.14 Troxler depth moisture gauge and Troxler ratemeter connected

CHAPTER V

RESULTS AND DISCUSSION

5.1 Results of the Soil Sample Analyses

The soil is predominantly clay at the sampled depths (Table 5.1). The average dry bulk density of the samples taken at the 15-cm depth was 1.2 g-cm^{-3}.

The chemical analyses showed very high phosphorous, potassium and nitrogen contents. Since the plot had been cropped the previous season, the high nitrogen content was unexpected. The samples may have been stored too long and microbial activities may have taken place. The electrical conductivity was low (0.4 to 1.0) and the pH range was 7.3 to 8.3 Table 5.2). A fertilizer application at levels maintaining the soil fertility probably would have been advised.

5.2 Results of the Water Analysis

The use of a 25-micron filter to provide adequate filtration of the irrigation water obtained from a dugout was an inadequate design. The upper limit of particle size of clay is 2-micron. This explained why the total residue remained essentially unchanged after irrigation water had passed through the filters (Table 5.3).

In fact, the interior clay coating observed in the drip lines, the large quantities of slurries collected at the drip-line terminals and the slightly decreasing discharge of the drip lines with time, were evidence of the design inadequacy.

5.2.1 The Laboratory Performance of the Viaflo Material

Previously unused drip lines samples, three m in length, showed the same general trend. Initially, higher discharges dropped signifi-

Table 5.1 The Physical Properties of the Soil Samples

Soil Sample	% Sand	% Silt	% Clay	Texture
S1a	31.7	33.5	34.8	clay loam
S1b	27.7	15.4	56.9	clay
S1c	22.7	20.7	56.6	clay
S2a	23.6	39.6	36.8	clay loam
S2b	14.0	23.2	62.8	clay
S2c	9.5	21.0	69.5	clay
S3a	14.0	27.6	58.4	clay
S3b	14.0	15.2	70.8	clay
S3c	5.8	5.4	88.8	clay
SB1a	34.0	31.2	34.8	clay loam
SB1b	35.6	29.6	34.8	clay loam
SB1c	21.6	31.6	46.8	clay
SB2a	21.2	35.2	43.6	clay
SB2b	16.8	27.2	56.0	clay
SB2c	10.8	21.2	68.0	clay
SB3a	20.8	34.6	44.6	clay
SB3b	22.8	35.2	42.0	clay
SB3c	18.8	18.8	62.4	clay
F1a	42.0	31.6	26.4	loam
F1b	40.0	35.6	24.4	loam
F1c	22.0	33.6	24.4	silt loam
F2a	25.2	35.2	39.6	clay loam
F2b	14.8	24.8	60.4	clay
F2c	9.6	19.2	71.2	clay
F3a	31.2	35.2	33.6	clay loam
F3b	24.0	35.6	40.4	clay
F3c	11.6	23.2	65.2	clay

Legand:
S = surface subplot
SB = subsurface subplot
F = furrow subplot
1, 2, 3 = moisture monitoring stations
a = 0 - 15-cm depth
b = 15 - 30-cm depth
c = 30 - 60-cm depth

Table 5.2 Chemical Properties of the Soil Samples

Soil Sample	$CaCO_3$	pH	Cond. mmhos/cm	NO_3-N ppm	NO_3-N kg/ha	NO_3-N level	Avail. P-ppm	Avail. K-ppm	Level K
S1a	V. low	7.3	0.6	32.6	58.6		29.0 (VH)	565	VH+
S1b	V. low	7.6	0.6	24.2	43.5	VH+	12.2	432	
S1c	V. low	7.7	0.5	22.0	96.4		9.0	355	
S2a	V. low	7.8	0.5	13.6	24.4		15.4 (H)	350	VH+
S2b	V. low	7.7	0.5	8.0	14.4	H	6.0	230	
S2c	Low	8.1	0.7	5.8	25.4		2.0	243	
S3a	Low	8.0	0.5	10.8	19.4		23.4 (VH)	429	VH+
S3b	Low	8.1	0.5	14.2	25.5	VH+	8.6	270	
S3c	Med.	8.3	0.6	20.8	91.1		0.4	215	
SB1a	V. low	7.4	0.5	17.2	31.0		26.4 (VH)	603	VH+
SB1b	V. low	7.3	0.5	13.8	24.8	VH+	9.0	317	
SB1c	V. low	7.6	0.6	17.6	77.1		8.0	295	
SB2a	V. low	7.9	0.4	19.0	34.1		20.6 (VH)	367	VH+
SB2b	V. low	7.8	0.5	11.6	20.8	VH+	4.4	245	
SB2c	V. low	7.9	0.6	7.8	34.1		0.8	264	
SB3a	V. low	7.9	0.5	10.6	19.0		16.0 (H)	455	VH+
SB3b	V. low	7.9	0.5	13.6	24.4	VH+	8.4	315	
SB3c	Med.	8.1	1.0	12.2	53.4		1.0	245	
F1a	N/A								
F1b	N/A								
F1c	N/A								
F2a	V. low	7.7	0.6	27.6	49.6		17.0 (H)	363	VH+
F2b	V. low	7.8	0.6	17.6	31.6	VH+	6.6	299	
F2c	Low	7.9	0.6	11.2	49.1		1.4	270	
F3a	V. low	7.8	0.5	13.8	24.8		19.8 (VH)	515	VH+
F3b	V. low	7.8	0.5	13.0	23.4	VH+	15.0	333	
F3c	Low	8.1	1.0	10.6	46.4		2.4	245	

Legend:

H = high
VH = very high
S = surface subplot
SB = subsurface subplot
F = furrow subplot
1, 2, 3 = moisture monitoring station

a = 0 - 15-cm depth
b = 15 - 30-cm depth
c = 30 - 60-cm depth

Table 5.3 The Physical and Chemical Properties of the Irrigation Water

i) Water directly from the dugout

Bicarbonate	83.00	mg/ℓ	HCO_3
Carbonate dissolved	26.00	mg/ℓ	CO_3
Nitrogen dissolved nitrate and nitrite	0.60	mg/ℓ	N
Hydroxide	0.00	mg/ℓ	OH
Alkalinity total	112.00	mg/ℓ	
pH	9.10		
*Residue total	294.00	mg/ℓ	
Hardness total $CaCO_3$	182.00	mg/ℓ	
Sodium extractable	25.00	mg/ℓ	
Magnesium extractable	29.00	mg/ℓ	
Phosphorous total P	0.05	mg/ℓ	
Sulphate dissolved	40.00	mg/ℓ	S04
Chloride soluble	27.00	mg/ℓ	
Potassium extractable	6.00	mg/ℓ	
Calcium extractable Ca	25.00	mg/ℓ	

ii) Metered unfiltered water from the furrow line

Bicarbonate	102.00	mg/ℓ	HCO_3
Carbonate dissolved	29.00	mg/ℓ	CO_3
Nitrogen dissolved nitrate and nitrite	0.09	mg/ℓ	N
Hydroxide	0.00	mg/ℓ	OH
Alkalinity total	132.00	mg/ℓ	
pH	9.20		
*Residual total	286.00	mg/ℓ	
Hardness total $CaCO_3$	178.00	mg/ℓ	
Sodium extractable	25.00	mg/ℓ	
Magnesium extractable	28.00	mg/ℓ	
Phosphorous total P	0.06	mg/ℓ	
Sulphate dissolved	43.00	mg/ℓ	
Chloride soluble	27.00	mg/ℓ	
Potassium extractable	6.00	mg/ℓ	
Calcium extractable Ca	25.00	mg/ℓ	

iii) Metered and filtered water from the surface and subsurface drip lines

Bicarbonate	151.00	mg/ℓ	HCO_3
Carbonate dissolved	0.00	mg/ℓ	CO_3
Nitrogen dissolved nitrate and nitrite	0.89	mg/ℓ	N
Hydroxide	0.00		OH
Alkalinity total	124.00		
pH	7.70		
*Residue total	286.00	mg/ℓ	
Hardness total $CaCO_3$	178.00	mg/ℓ	
Sodium extractable	25.00	mg/ℓ	
Magnesium extractable Mg	28.00	mg/ℓ	
Phosphorous total P	0.06	mg/ℓ	
Sulphate dissolved	43.00	mg/ℓ	
Chloride soluble	27.00	mg/ℓ	
Potassium extractable	6.00		
Calcium extractable Ca	25.00		

cantly with time and then stabilized. In a few cases, discharge was high initially, dropped later but increased again (Fig. 5.1)

At the same operating head and observation interval (30 minutes), discharge differed considerably for different samples. Generally, higher discharge was recorded for higher pressures except in some unusual cases where discharge was greater at low pressures than at high pressures (Figs. 5.1, 5.2, 5.3).

A critical operating head at which such previously unused drip-line samples failed physcially was found to be 4.75 m on the average. At the critical head, most of the tested samples ruptured along the seams.

For materials left dripping continuously until equilibrium conditions were attained after two days before measurements, operating head appeared to correlate linearly with discharge. But different linear relationships occurred for different samples. Such materials stood pressures above the critical value for previously unused samples. The critical pressure was not determined in this case (Fig. 5.4).

Thus, by gradually increasing the operating head over an extended period (two days), drip lines would probably stand high pressures and operating pressures would probably correlate with discharge in a linear manner.

5.2.2 The Field Performance of the Drip Lines

Field results indicated that the drip lines had a more uniform average discharge at constant head for observation intervals greater than 24 hours.

At the beginning of the study, higher discharge rates were recorded on both trickle irrigation systems, but discharge considerably stabilized with time (Fig. 5.5).

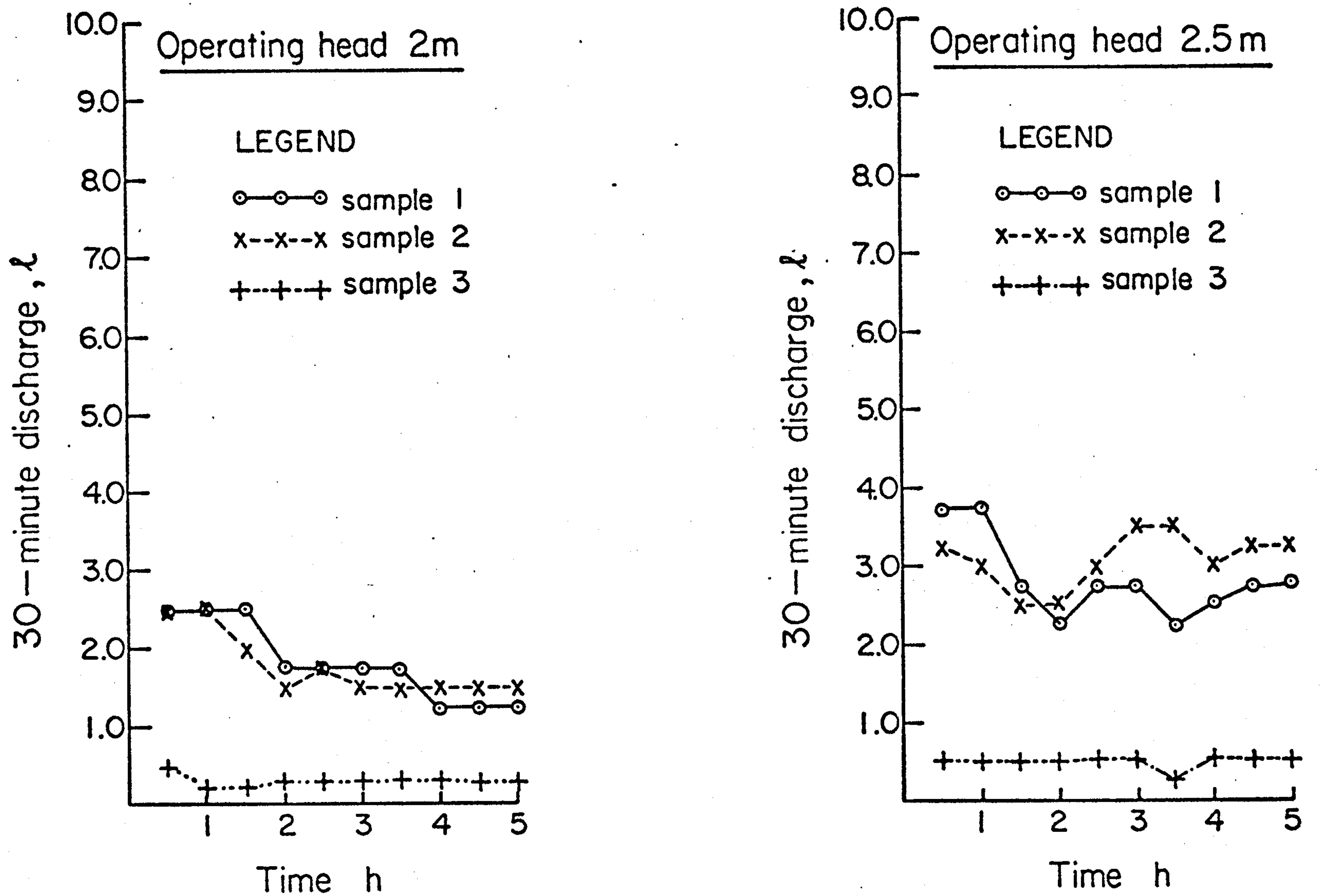


Fig. 5.1 The time dependency of discharge at two operating heads (2 m , 2.5 m)

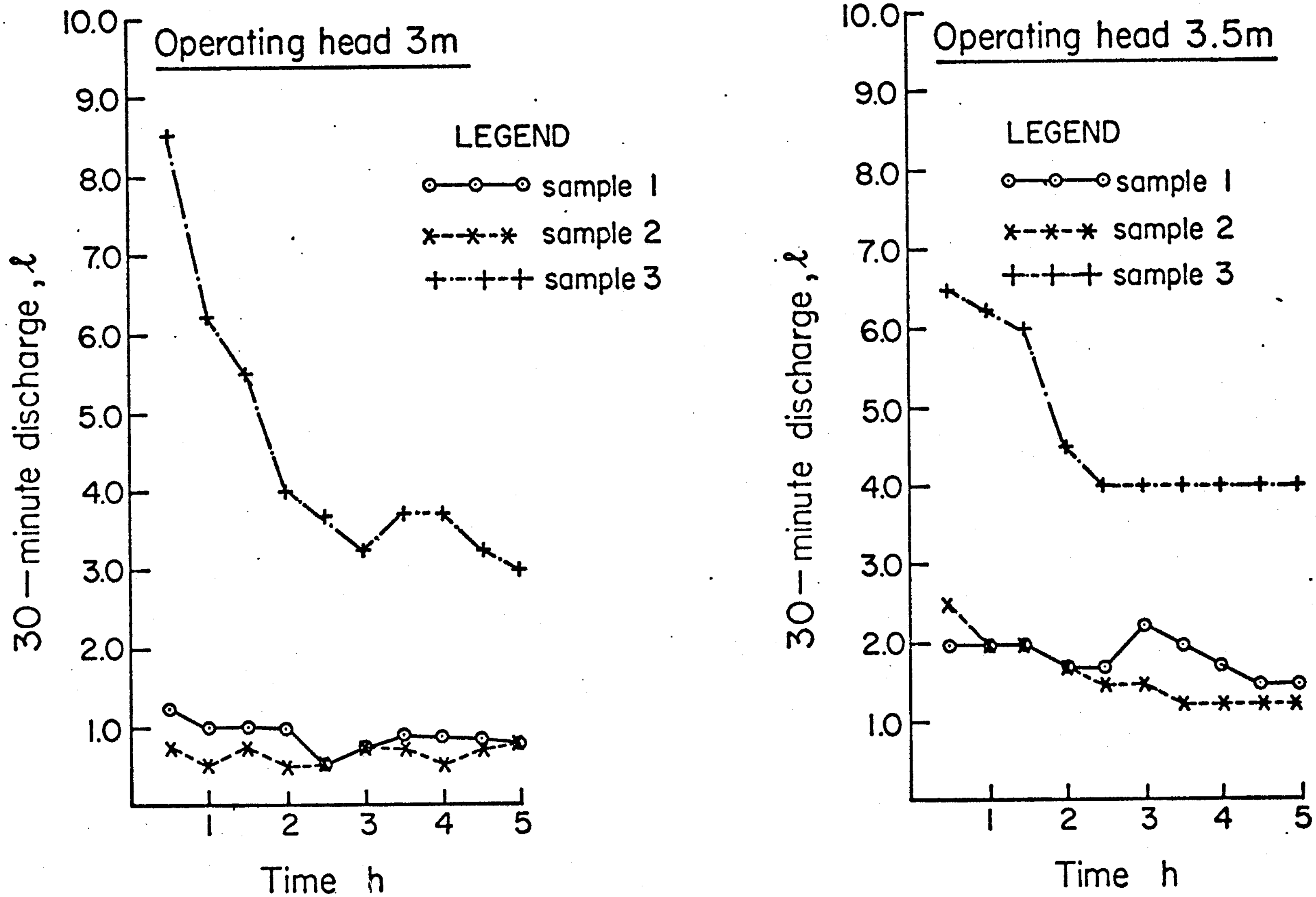


Fig. 5.2 The time dependency of discharge at two operating head (3m, 3.5m)

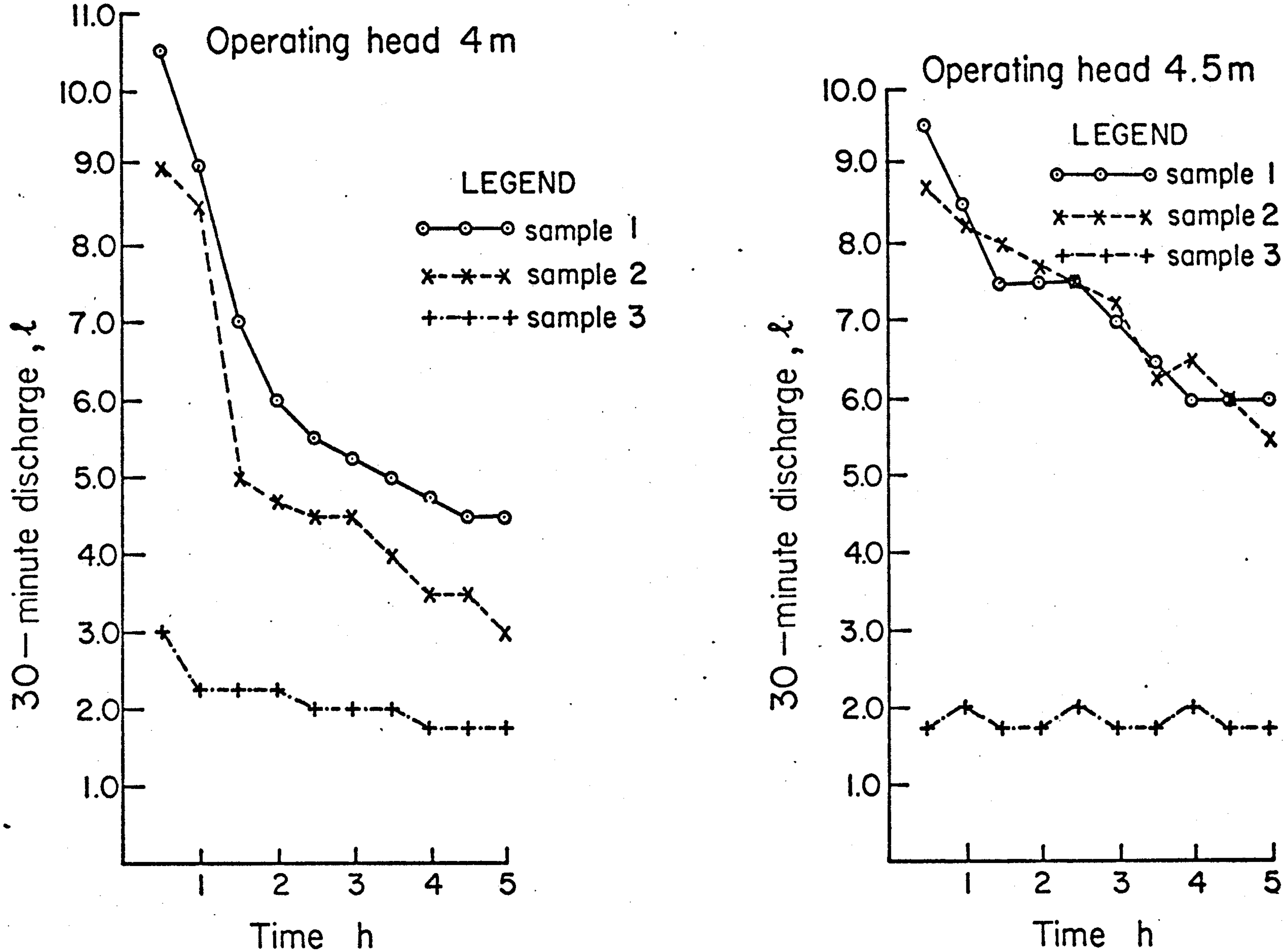


Fig. 5.3 The time dependency of discharge at two operating heads (4m, 4.5m)

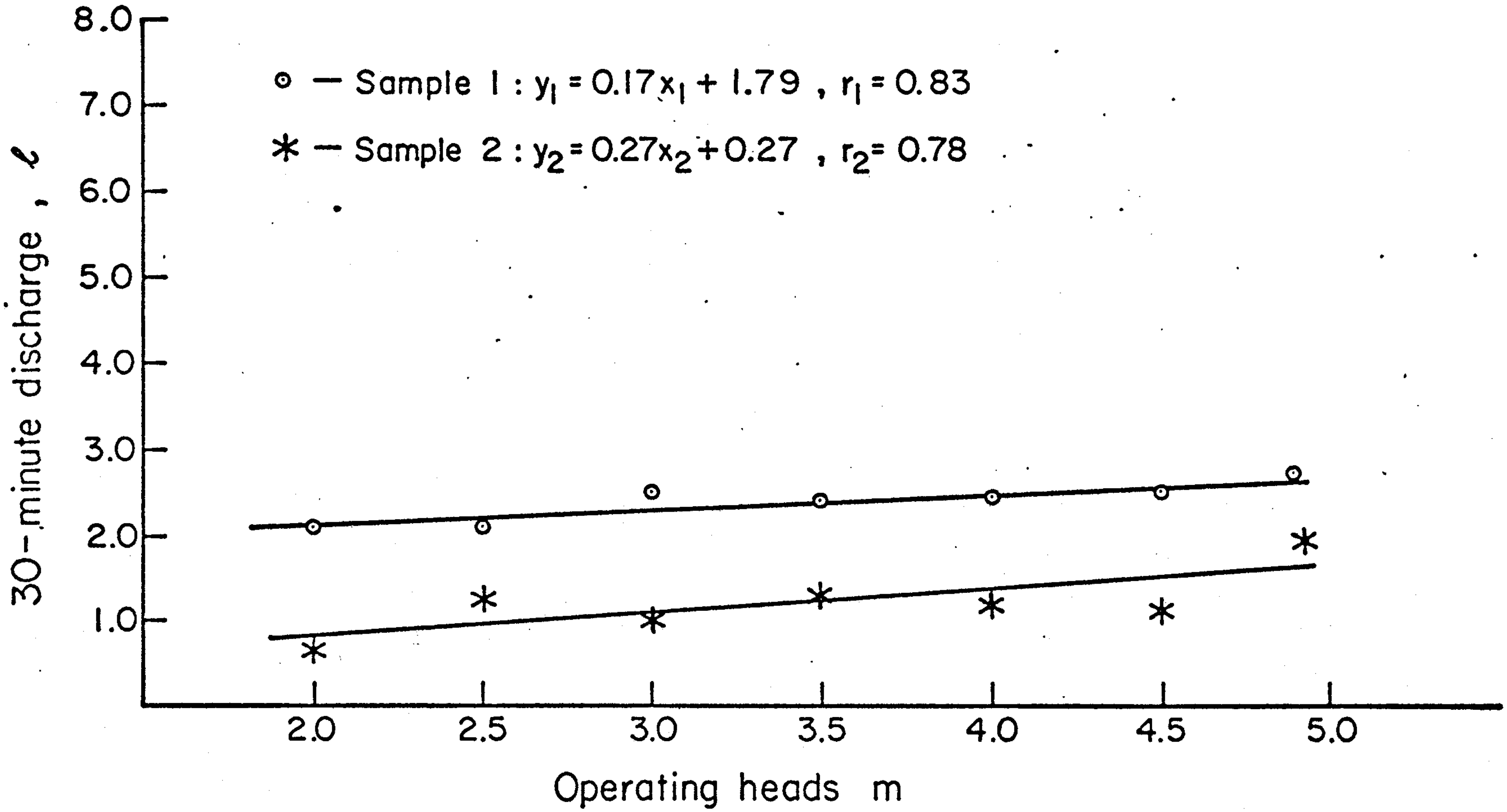


Fig. 5.4 The discharge dependency of variable heads for two test samples dripping continuously for two days before measurements.

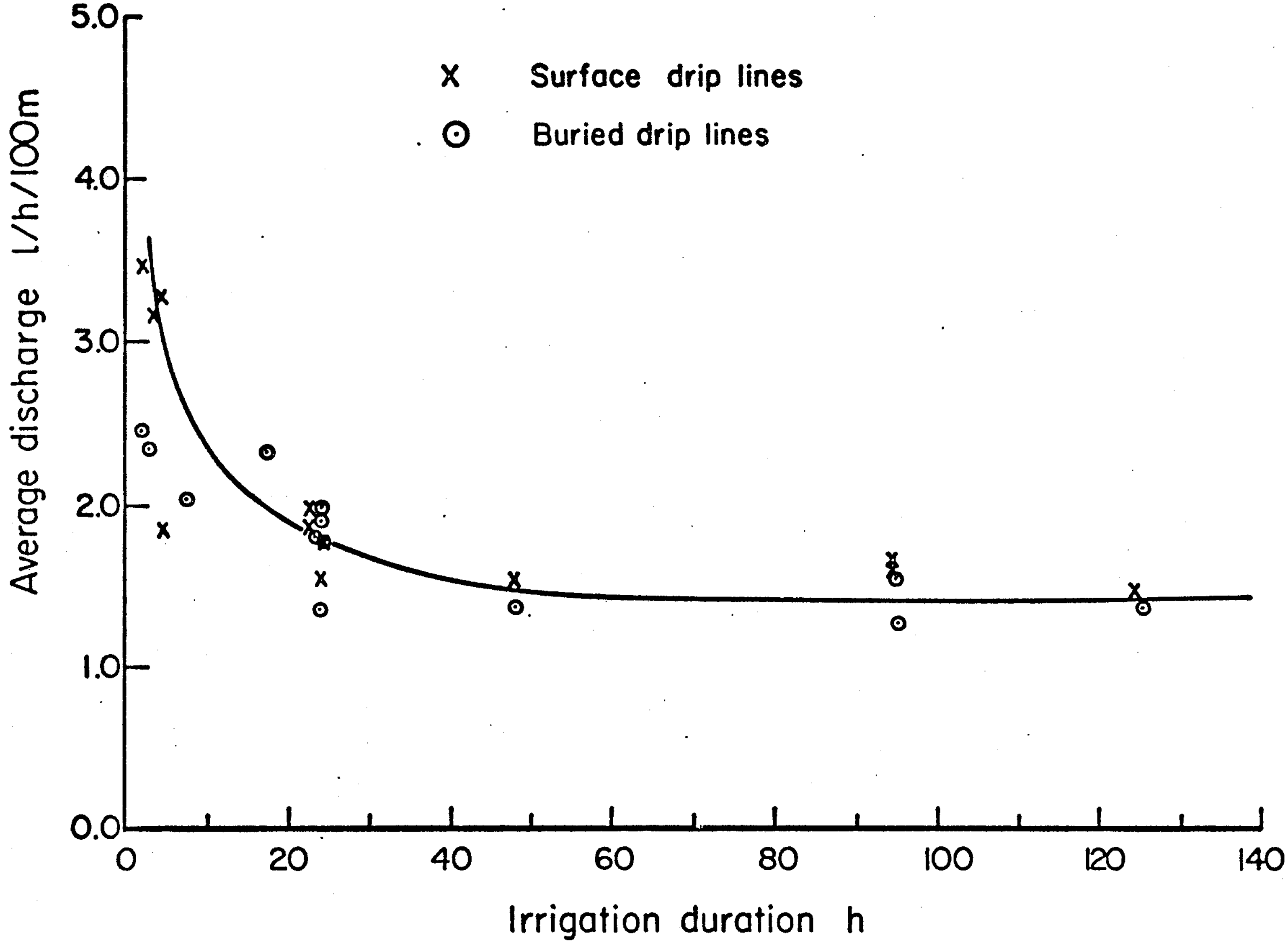


Fig. 5.5 Field drip-line discharge at various observation intervals.

5.2.3 The Irrigation Periods and Amounts

The irrigation periods and amounts are shown in Table 5.4. A total of 4254 ℓ and 4735 ℓ of water was applied to the surface and subsurface treatments respectively. A total of 4966 ℓ was applied to the furrow system during the two irrigation periods, occurring one month apart.

5.2.4 The Soil Moisture Profile

5.2.4.1 The surface-irrigated subplot

Access tubes S3, S7, and S12 were situated along the drip line (a), while tubes S5, S9, and S14 were located along the drip line (b). Tube S1 was situated along the non-irrigated crop row in the buffer zone. Other tubes were located along the interrow spaces (Fig. 4.7).

Along the irrigated rows, fairly constant moisture contents of 480 g/ℓ and 540 g/ℓ were maintained at the 60-cm and 98-cm depths respectively (Fig. 5.6, Table 5.5). In many cases, in stations II and III, a nearly uniform moisture range 450 to 490 g/ℓ was maintained within the 15-cm and 60-cm depths (Fig. 5.7, Table 5.6). In station I, considerably drier conditions were found (Table 5.5).

Along the interrow spaces, moisture contents at the 98-cm, 60-cm and 30-cm depths remained essentially unchanged at 500 g/ℓ, 450 g/ℓ and 420 g/ℓ respectively (Fig. 5.8, Table 5.7). In tube S8, the moisture at the 30-cm depth exceeded that at the 60-cm depth (Table 5.8). In tube S13, the moisture content at the 15-cm depth exceeded that at the 30-cm depth (Table 5.9). The effective root zone and water contribution from adjacent drip lines probably explain this situation. In almost all cases, considerable moisture fluctuations

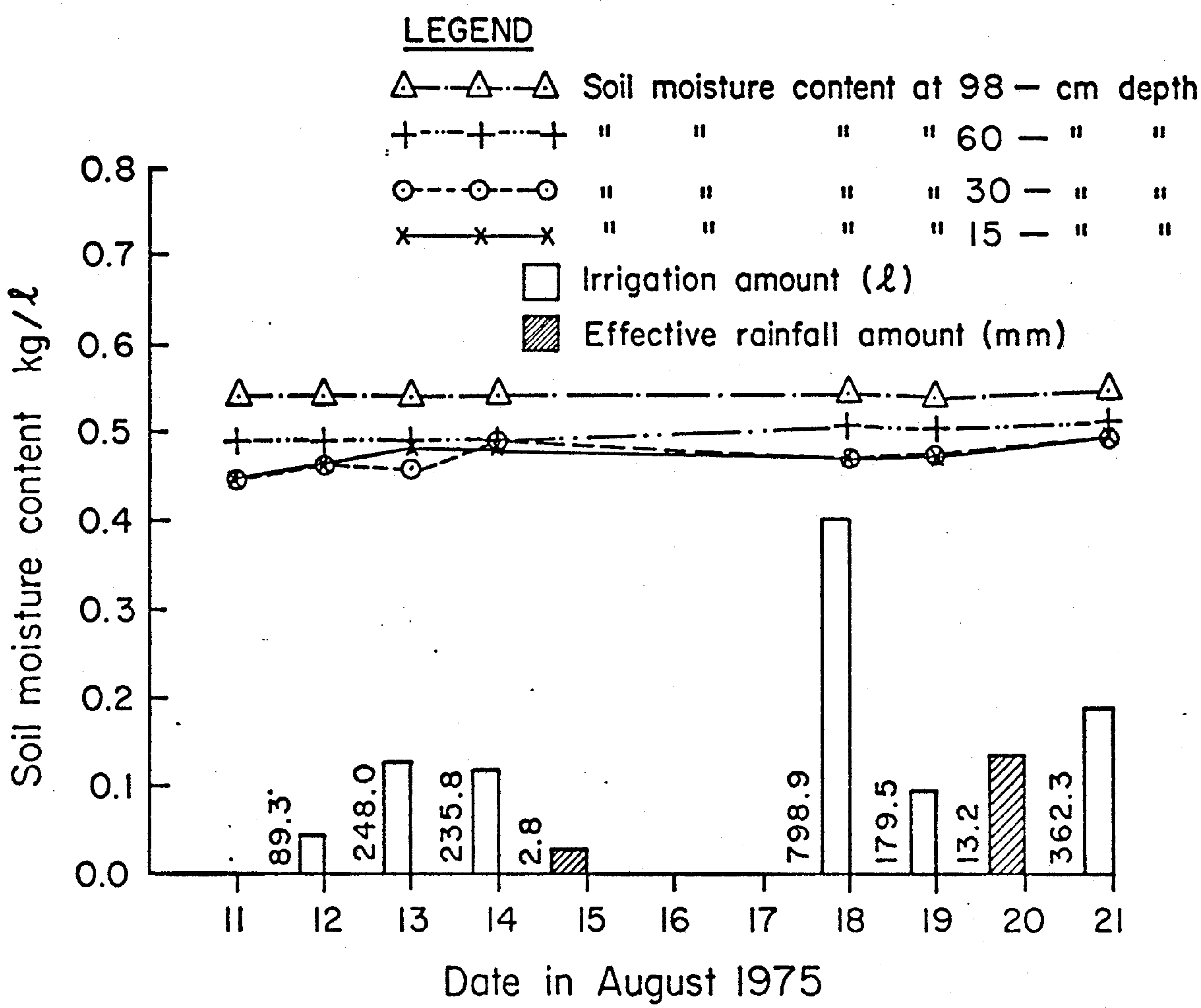


Fig. 5.6 Moisture profile for access tube S14, installed close to the irrigated crop row

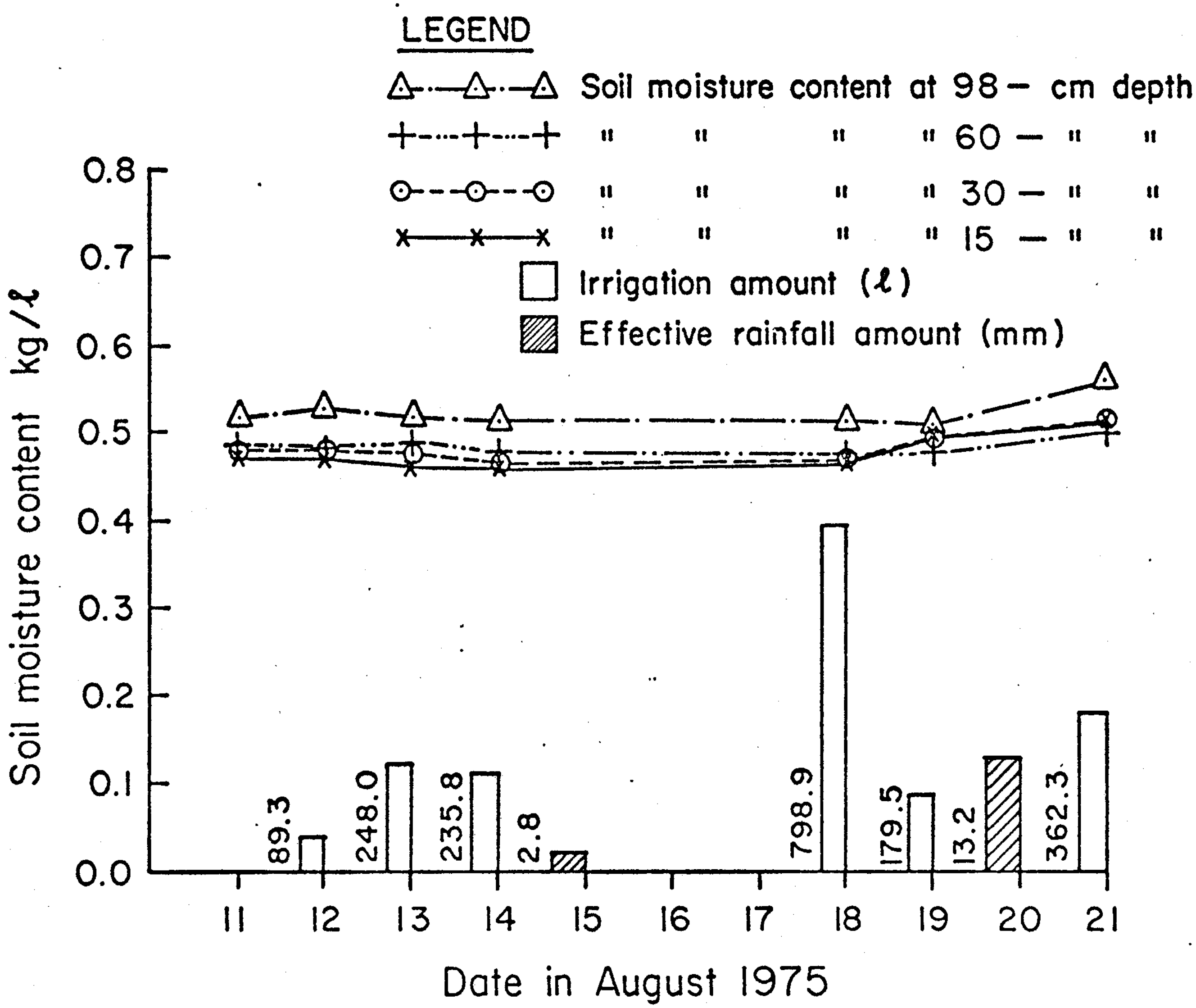


Fig.5.7 Moisture profile for access tube S7, installed close to the irrigated crop row

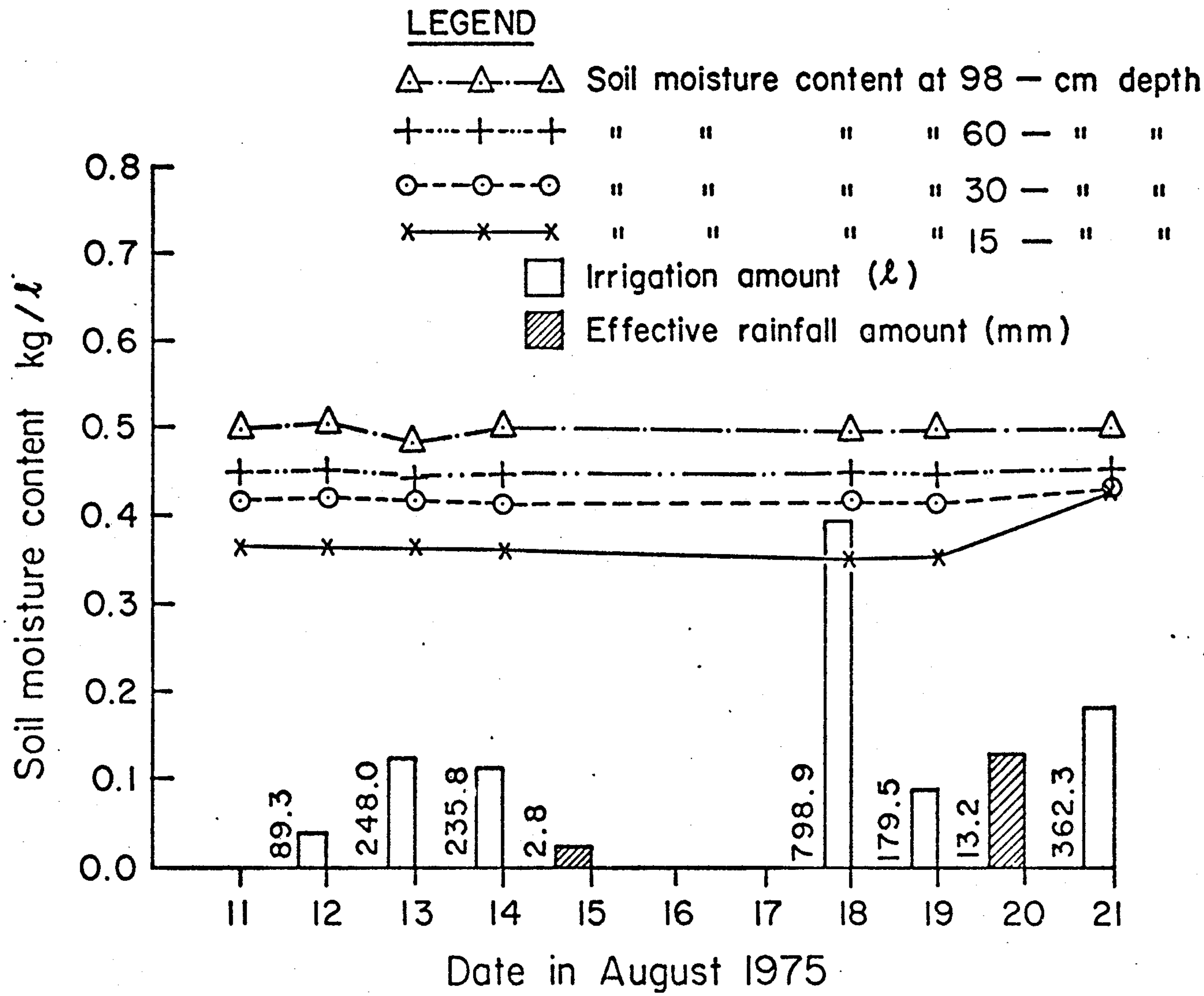


Fig. 5.8 Moisture profile for access tube S4, in the inter-row space

Table 5.4 Irrigation Frequency and Amount, Drip-line Discharge Rates (Surface and Subsurface)

Date	Irrigation Duration (h)	Irrigation Amount (ℓ)	Drip-line Discharge Rate* (ℓ/h/100 m)	Date	Irrigation Duration (h)	Irrigation Amount (ℓ)	Drip-line Discharge Rate (ℓ/h/100 m)
14/7	2.00	26.8	2.45	16/7	2.00	38.3	3.48
15/7	17.50	222.4	2.31	17/7	----	291.4	----
30/7	3.00	38.6	2.35	22/7	4.50	80.7	3.27
6- 7/8	24.00	244.7	1.97	23/7	3.75	65.0	3.16
7- 8/8	23.66	235.1	1.80	6- 7/8	24.00	255.2	1.94
11/8	7.90	89.3	2.06	7- 8/8	22.16	119.2	1.84
12-13/8	23.83	248.1	1.89	11/8	5.33	53.9	1.84
13-14/8	24.06	235.9	1.79	12-13/8	23.83	249.0	1.90
14-18/8	95.76	798.9	1.52	13-14/8	24.06	235.1	1.78
18-19/8	24.00	175.5	1.37	14-18/8	95.80	870.2	1.66
19-21/8	48.16	362.3	1.37	18-19/8	24.00	200.0	1.52
21-26/8	125.80	919.3	1.33	19-21/8	48.16	401.3	1.52
5- 9/9	95.66	652.9	1.24	21-26/8	124.33	962.2	1.41
				5- 9/9	95.66	813.1	1.54
TOTAL		4253.90				4734.5	

*Total length of drip lines = 548.64 m
(rate = ℓ/h/100 m drip-line length)

Table 5.5 Moisture Contents (g/ℓ) for Access Tube S3, Close to the Irrigated Crop Row

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	I	361	353	483	531	------	-----
12/8		356	355	489	533	89.33	-----
13/8		351	355	489	532	240.00	-----
14/8		349	350	350	484	235.86	-----
15/8		---	---	---	---	------	2.79
18/8		352	356	477	523	798.92	-----
19/8		352	358	477	528	179.53	-----
20/8		---	---	---	---	------	13.20
21/8		394	383	489	527	352.32	-----

Table 5.6 Moisture Contents (g/ℓ) for Access Tube S9, Installed Close to the Irrigated Crop Row

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	II	433	466	470	497	------	-----
12/8		444	470	472	498	89.33	-----
13/8		467	507	502	507	248.00	-----
14/8		478	504	503	508	235.86	-----
15/8		---	---	---	---	------	2.79
18/8		474	501	493	494	798.92	-----
19/8		468	497	490	497	179.53	-----
20/8		---	---	---	---	------	13.20
21/8		482	513	527	570	362.32	-----

Table 5.7 Moisture Contents (g/ℓ) for Access Tube S10, in the Interrow Space

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	II	392	423	445	490	------	-----
12/8		393	427	452	496	89.33	-----
13/8		390	423	444	487	248.00	-----
14/8		379	429	449	488	235.86	-----
15/8		---	---	---	---	------	2.79
18/8		387	425	443	490	798.92	-----
19/8		377	427	448	488	179.53	-----
20/8		---	---	---	---	------	13.20
21/8		425	435	446	501	362.32	-----

Table 5.8 Moisture Contents (g/ℓ) for Access Tube S8, in the Interrow space

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	II	422	462	440	494	-----	-----
12/8		422	462	448	494	89.33	-----
13/8		413	458	443	493	248.0	-----
14/8		412	463	445	500	235.86	-----
15/8		---	---	---	---	-----	2.79
18/8		412	460	443	493	798.92	-----
19/8		407	458	438	493	179.53	-----
20/8		---	---	---	---	-----	13.20
21/8		472	498	455	534	362.32	-----

Table 5.9 Moisture Contents (g/ℓ) for Access Tube S13, in the Interrow Space

Date	Monitoring Station	Soil Depth (cm)				Water Applied (ℓ)	Rainfall (mm)
		15	30	60	98		
11/8	III	436	419	474	527	------	-----
12/8		434	419	481	525	89.33	-----
13/8		434	422	473	527	248.00	-----
14/8		432	423	470	525	235.86	-----
15/8		---	---	---	---	------	2.79
18/8		425	421	462	515	798.92	
19/8		424	423	460	516	179.53	-----
20/8		---	---	---	---	------	13.20
21/8		470	459	458	515	362.32	-----

occurred at the 15-cm depth (Fig. 5.9).

On the non-irrigated crop row S1, fairly constant moisture levels of 410 g/ℓ and 470 g/ℓ were maintained at the 60-cm and the 98-cm depths respectively. A slightly decreasing average moisture content of 370 g/ℓ was obtained at the 30-cm depth. A considerable moisture depletion was found at the 15-cm depth (Fig. 5.10).

Moisture distribution patterns plotted at the 100-, 200-, 300-, 400-, 450-, and 500-g/ℓ levels for one day and four days of continued irrigation indicated slight moisture distribution pattern changes during one day of continuous irrigation (Fig. 5.11). Except for considerable moisture increases along the drip line (a), in station I and along the drip line (b), in station II, at the 15-cm to 60-cm depths, moisture patterns remained essentially unchanged after four days of continuous irrigation (Fig. 5.12). During two days of continuous irrigation, a considerable moisture depletion occurred between the 15-cm and 98-cm depths, in the non-irrigated crop row S1. Between the 15-cm and 30-cm depths, in stations II and III, moisture contents along the drip line (b) increased significantly (Table 5.10).

5.2.4.2 The subsurface subplots

Access tubes B3, B7, and B12 were located along drip line (a), while tubes B5, B9, and B14 were located along drip line (b). Tube B1 was situated on the non-irrigated row. Other tubes were situated along the interrow spaces (Fig. 4.8).

Along the irrigated rows, fairly constant moisture levels of 500 g/ℓ and 440 g/ℓ were maintained at the 98-cm and 60-cm depths respectively (Fig. 5.13 , Table 5.12). A nearly uniform moisture content was maintained within the 30-cm and 60-cm depths, in some cases. (Tables

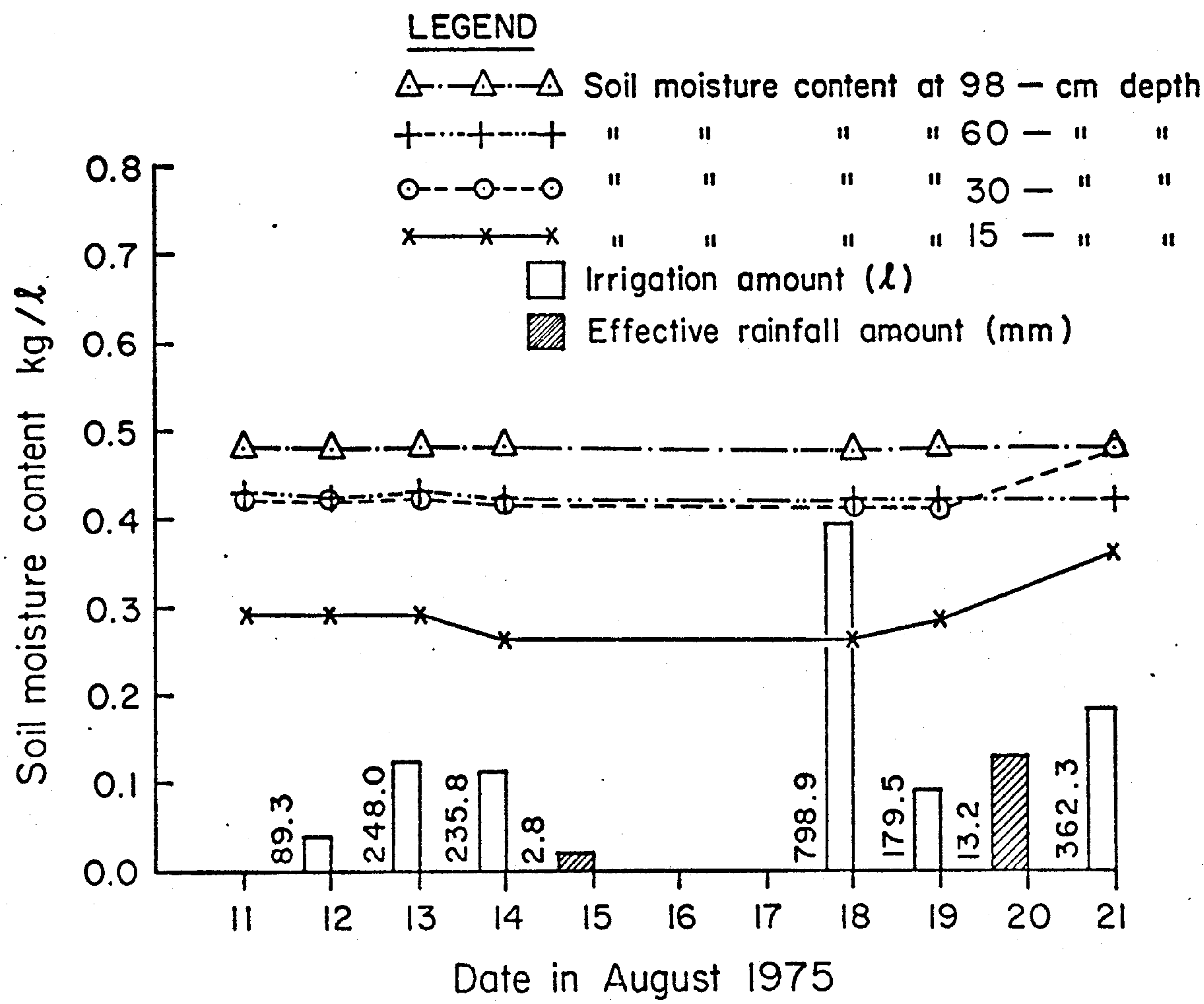


Fig. 5.9 Moisture profile for access tube S2, in the inter row space

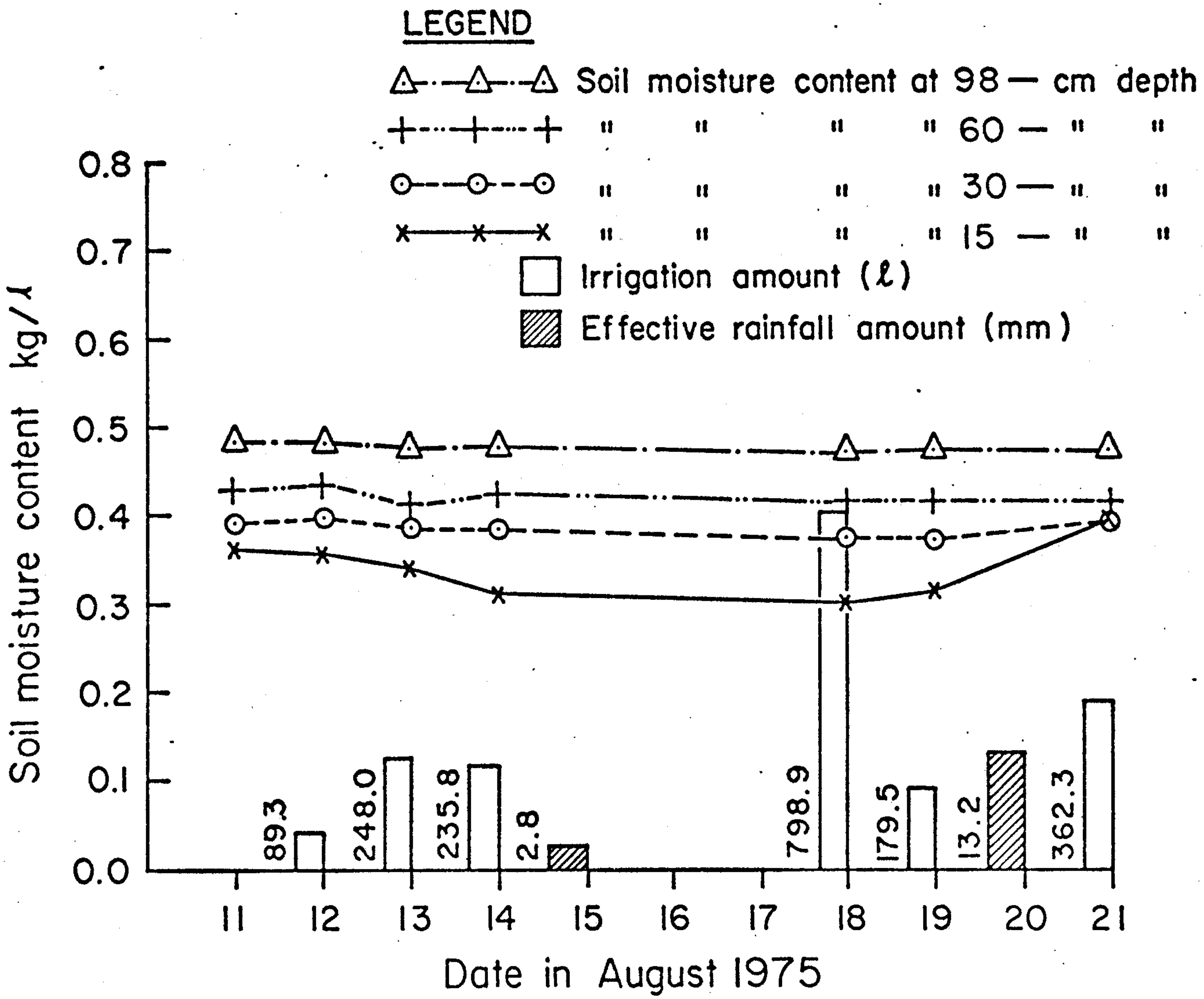


Fig. 5.10 Moisture profile for access tube S1, in the non-irrigated crop row

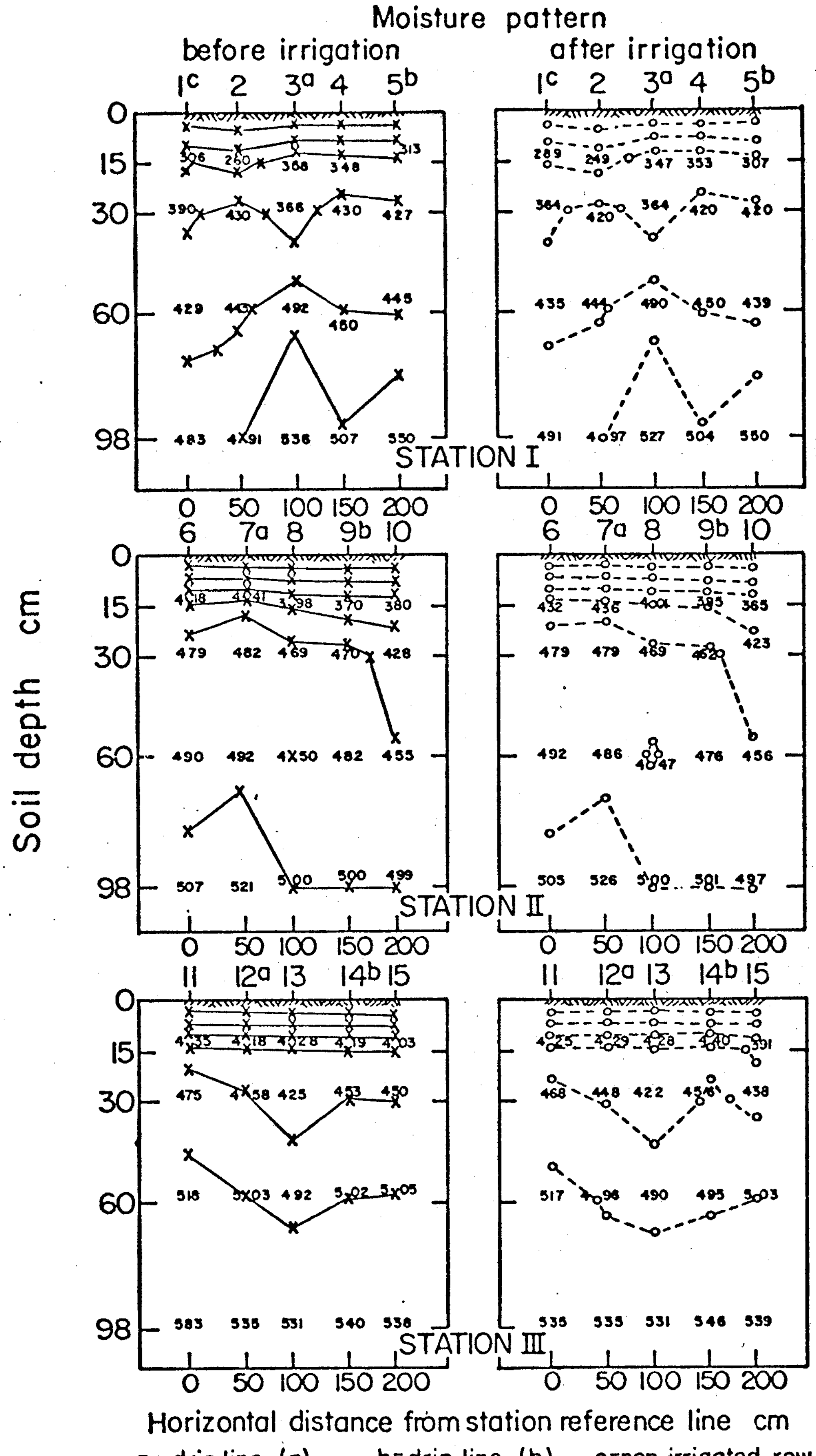


Fig. 5.11 Moisture distribution patterns before and after one day of continuous irrigation (surface)

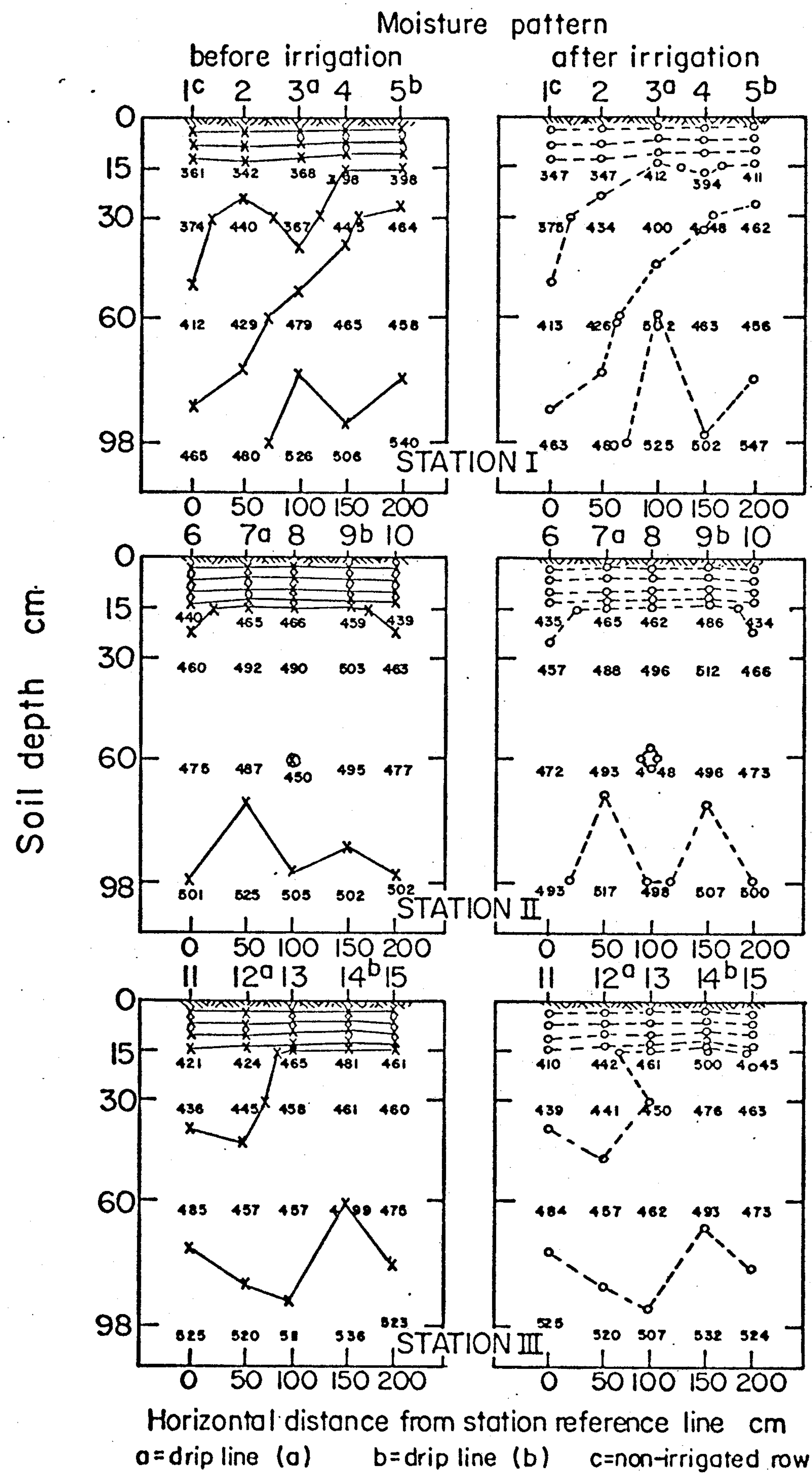


Fig. 5.12 Moisture distribution patterns before and after four days of continuous irrigation (surface)

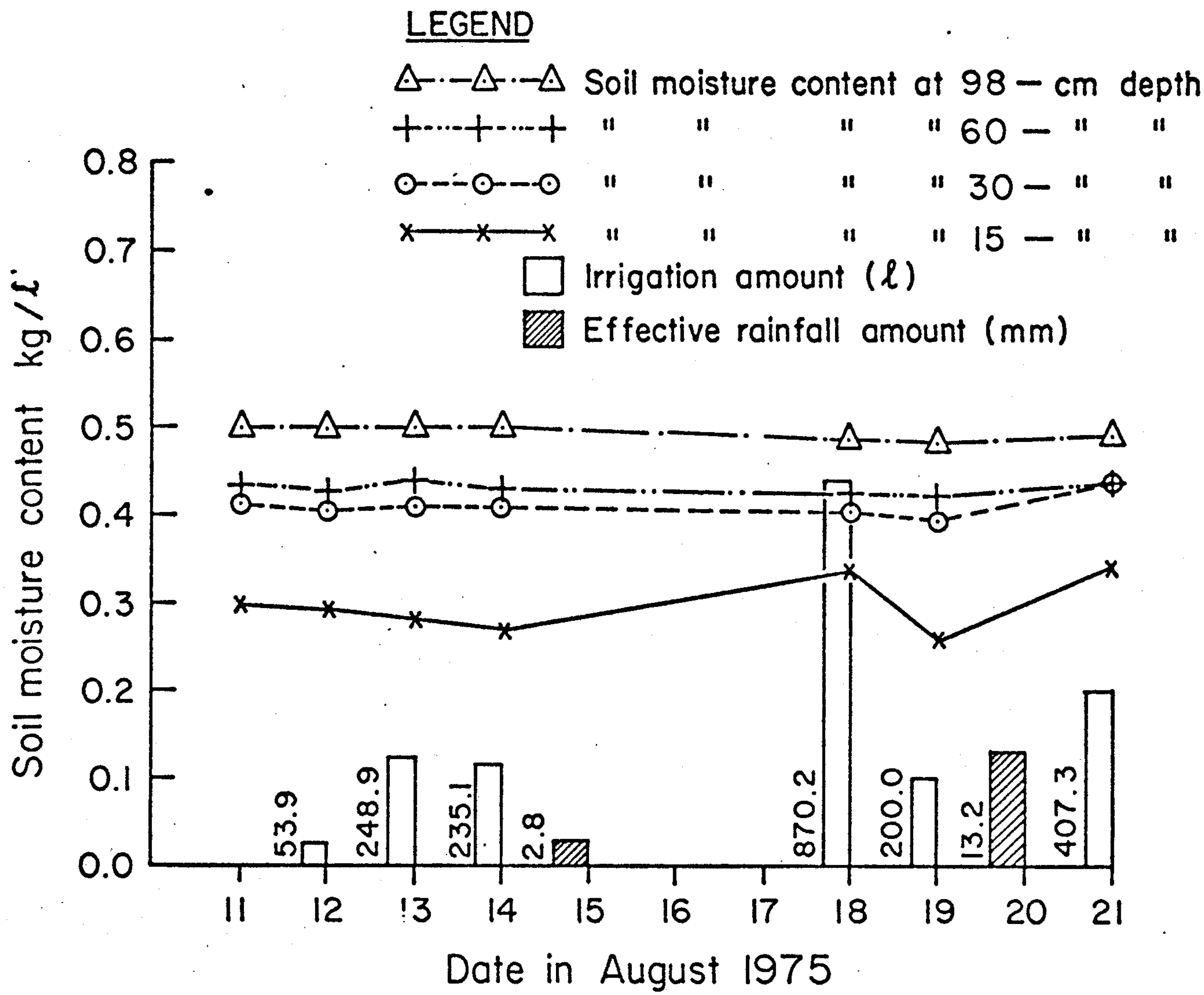


Fig. 5.13 Moisture profile for access tube B3, in the irrigated row (subsurface).

Table 5.10 Moisture Contents (g/ℓ) Before and After Two Days of Continuous Irrigation (Surface Subplot)

Access Tube	Station	Soil Depth (cm) 15	30	60	98
1	I	(355) 313	(390) 379	(431) 422	(483) 477
2		(291) 264	(427) 421	(430) 425	(487) 481
3(a)		(356) 349	(355) 350	(489) 484	(533) 531
4		(369) 362	(420) 417	(451) 450	(505) 500
5(b)		(341) 334	(416) 413	(426) 420	(551) 546
6	II	(444) 449	(473) 464	(481) 479	(501) 499
7(a)		(472) 459	(485) 474	(486) 483	(529) 518
8		(422) 412	(462) 463	(448) 445	(494) 500
9(b)		(441) 478	(470) 504	(472) 503	(498) 508
10		(393) 379	(427) 429	(452) 449	(496) 488
11	III	(436) 422	(455) 440	(511) 506	(536) 534
12(a)		(434) 424	(451) 443	(487) 485	(530) 531
13		(435) 432	(419) 423	(481) 470	(525) 523
14(b)		(462) 479	(458) 487	(489) 486	(539) 540
15		(405) 392	(429) 429	(490) 487	(534) 532

( ) moisture before irrigation
(a) access tubes in drip-line (a)
(b) access tubes in drip-line (b)

5.11, 5.12). In almost all cases, moisture fluctuations at the 15-cm depth was considerable (Fig. 5.13, Table 5.11).

Along the interrow spaces, the moisture level at the 98-cm depth was fairly constant at 510 g/ℓ. At the 60-cm and 30-cm depths, the average moisture contents were 450 g/ℓ and 410 g/ℓ respectively (Fig. 5.14, Table 5.13). In a few cases, moisture at the 30-cm depth was nearly equal to that at the 60-cm depth (Fig. 5.15). In almost all cases, moisture fluctuation at the 15-cm depth was considerable (Fig. 5.15, Table 5.14).

Along the non-irrigated row, fairly constant moisture levels of 500 g/ℓ, 420 g/ℓ, and 400 g/ℓ were maintained at the 98-cm 60-cm and 30-cm depths respectively. Significant moisture depletion occurred at the 15-cm depth (Fig. 5.16).

Moisture distribution patterns plotted at the 100-,200-, 300-,400-, 450-, and 500- g/ℓ levels, for one day, two days and four days of continuous irrigation indicated slight moisture pattern changes during one day and four days of irrigation (Figs. 5.17, 5.19). A significant moisture depletion occurred at the 30-cm depth but only slightly in the 60-cm depth, in station II, during two days of continuous irrigation (Fig. 5.18).

5.2.4.3 Furrow-irrigated subplot

Along the furrows and crop rows, except in the interrow space in the buffer zone 6(c), moisture contents increased considerably at all depths during the first irrigation. During the second irrigation, along the furrows, moisture contents at all depths increased reasonably. But along the crop rows, moisture content increases were confined within the 15-cm to 60-cm depths in station I, and within the 15-cm to 30-cm

Table 5.11 Moisture Contents (g/ℓ) for Access Tube B9, in the Crop Row (Subsurface)

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	II	346	453	444	515	------	-----
12/8		323	447	440	511	53.86	-----
13/8		328	448	448	507	248.95	-----
14/8		321	439	440	502	235.14	-----
15/8		---	---	---	---	------	2.79
18/8		314	437	437	494	870.16	-----
19/8		315	440	436	499	200.00	-----
20/8		---	---	---	---	------	13.20
21/8		397	481	445	499	401.28	-----

Table 5.12 Moisture Contents (g/ℓ) for Access Tube B7, in the Crop Row (Subsurface)

Date	Monitoring Station	Soil Depth (cm) 15	30	60	98	Water Applied (ℓ)	Rainfall (mm)
11/8	II	431	458	459	511	------	-----
12/8		427	453	450	508	53.86	-----
13/8		434	459	452	512	248.95	-----
14/8		426	449	445	508	235.14	-----
15/8		---	---	---	---	------	2.79
18/8		428	445	429	503	870.16	-----
19/8		425	447	430	497	200.00	-----
20/8		---	---	---	---	------	13.20
21/8		468	485	430	498	401.28	-----

Table 5.13 Moisture Contents (g/ℓ) for Access Tube B13, in the Interrow Space (Subsurface)

Date	Monitoring Station	Soil Depth (cm)				Water Applied (ℓ)	Rainfall (mm)
		15	30	60	98		
11/8	III	387	414	463	521	------	-----
12/8		380	418	459	521	53.86	-----
13/8		367	415	468	521	248.95	-----
14/8		353	413	455	517	235.14	-----
15/8		---	---	---	---	------	2.79
18/8		339	409	452	505	870.16	-----
19/8		340	406	450	509	200.00	-----
20/8		---	---	---	---	------	13.20
21/8		387	416	452	509	401.28	-----

Table 5.14 Moisture Contents (g/ℓ) for Access Tube B4, in the Interrow Space (Subsurface)

Date	Monitoring Station	Soil Depth (cm)				Water Applied (ℓ)	Rainfall (mm)
		15	30	60	98		
11/8	I	225	444	435	500	------	-----
12/8		239	434	428	503	53.86	-----
13/8		251	431	433	501	248.95	-----
14/8		232	428	430	502	235.14	-----
15/8		---	---	---	---	------	2.79
18/8		194	413	421	495	870.16	-----
19/8		189	414	426	488	200.00	-----
20/8		---	---	---	---	------	13.20
21/8		220	491	443	494	401.28	-----

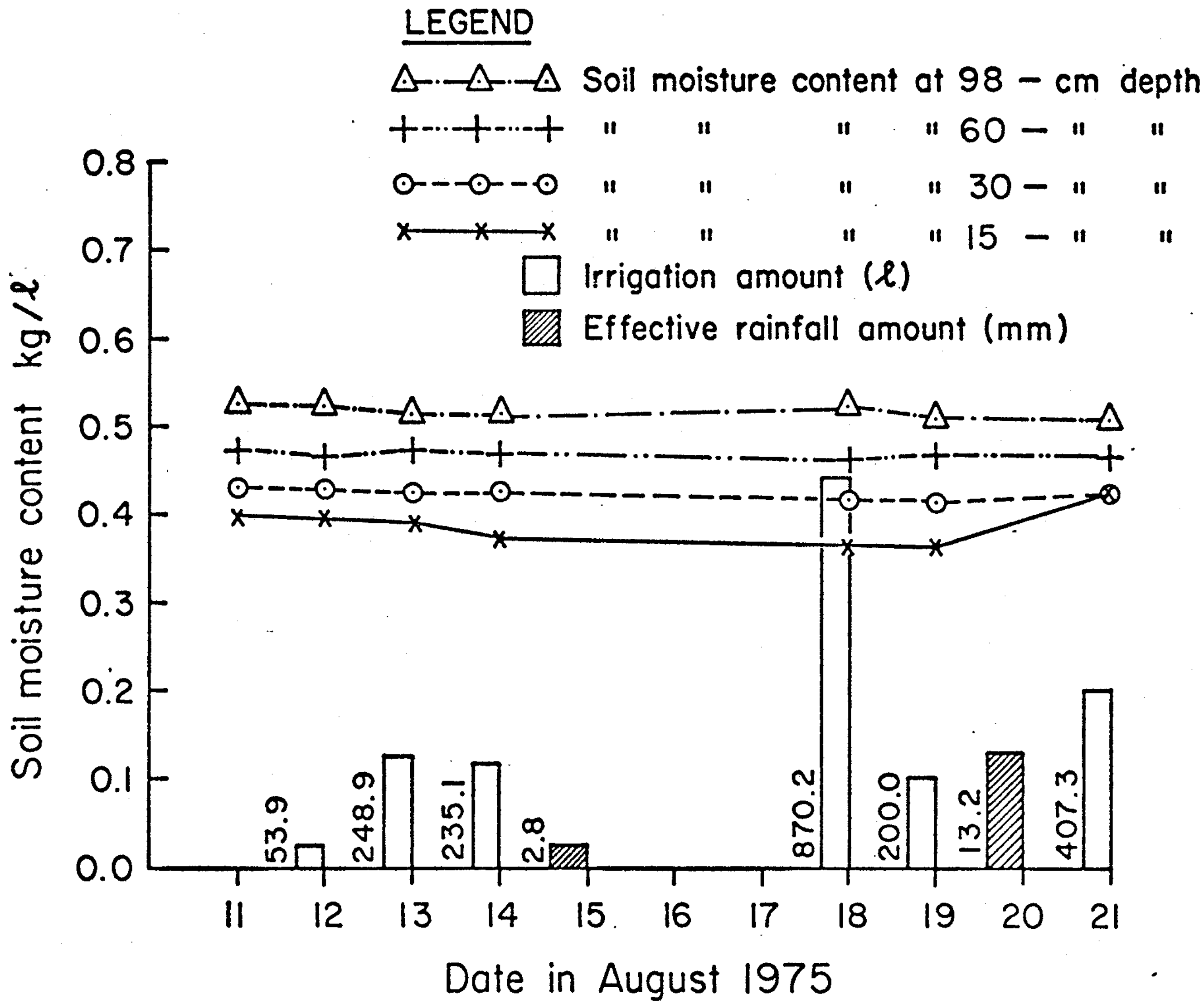


Fig. 5.14 Moisture profile for access tube B15, in the interrow space (subsurface)

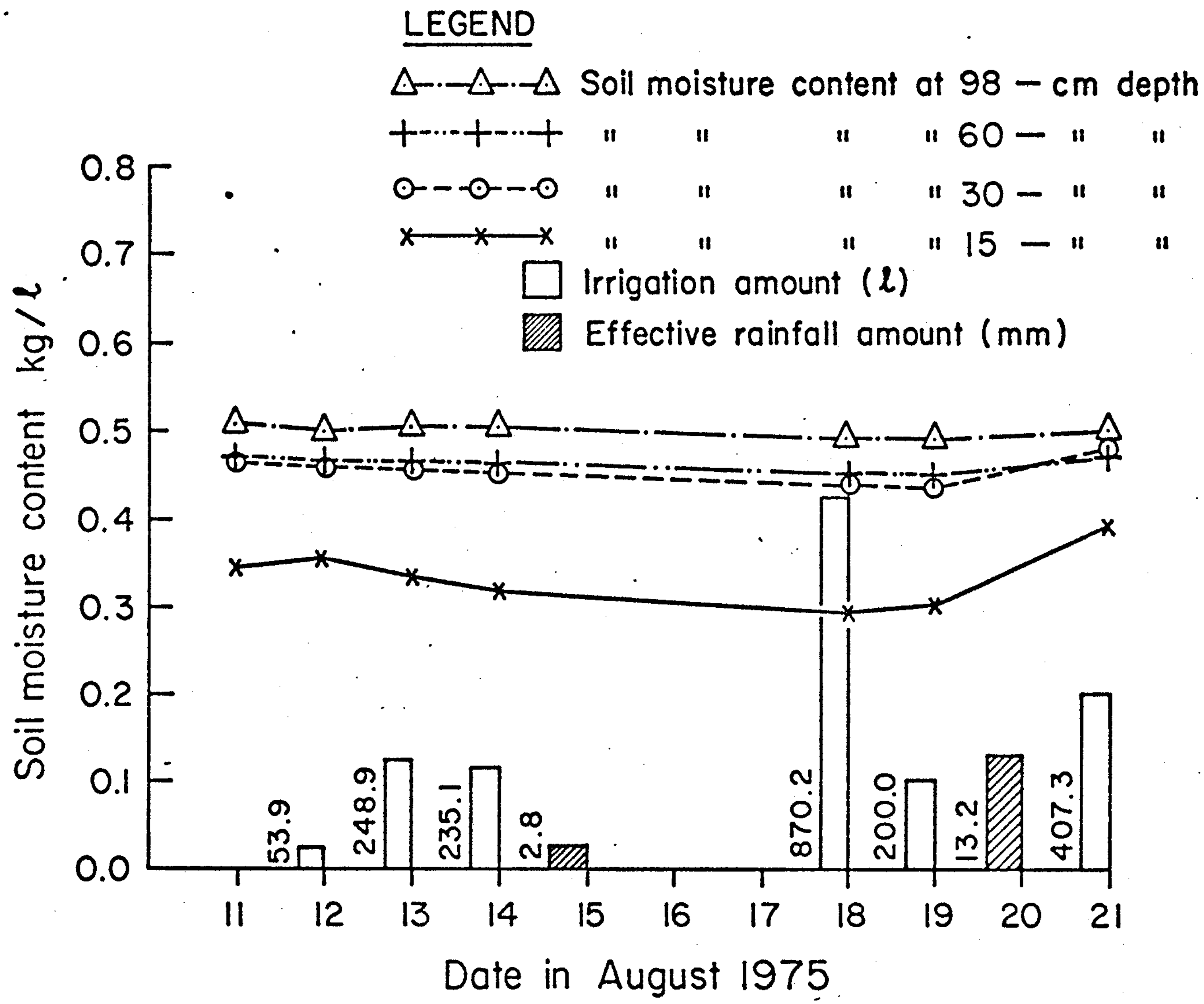


Fig. 5.15 Moisture profile for access tube B 8, in the interrow space (subsurface).

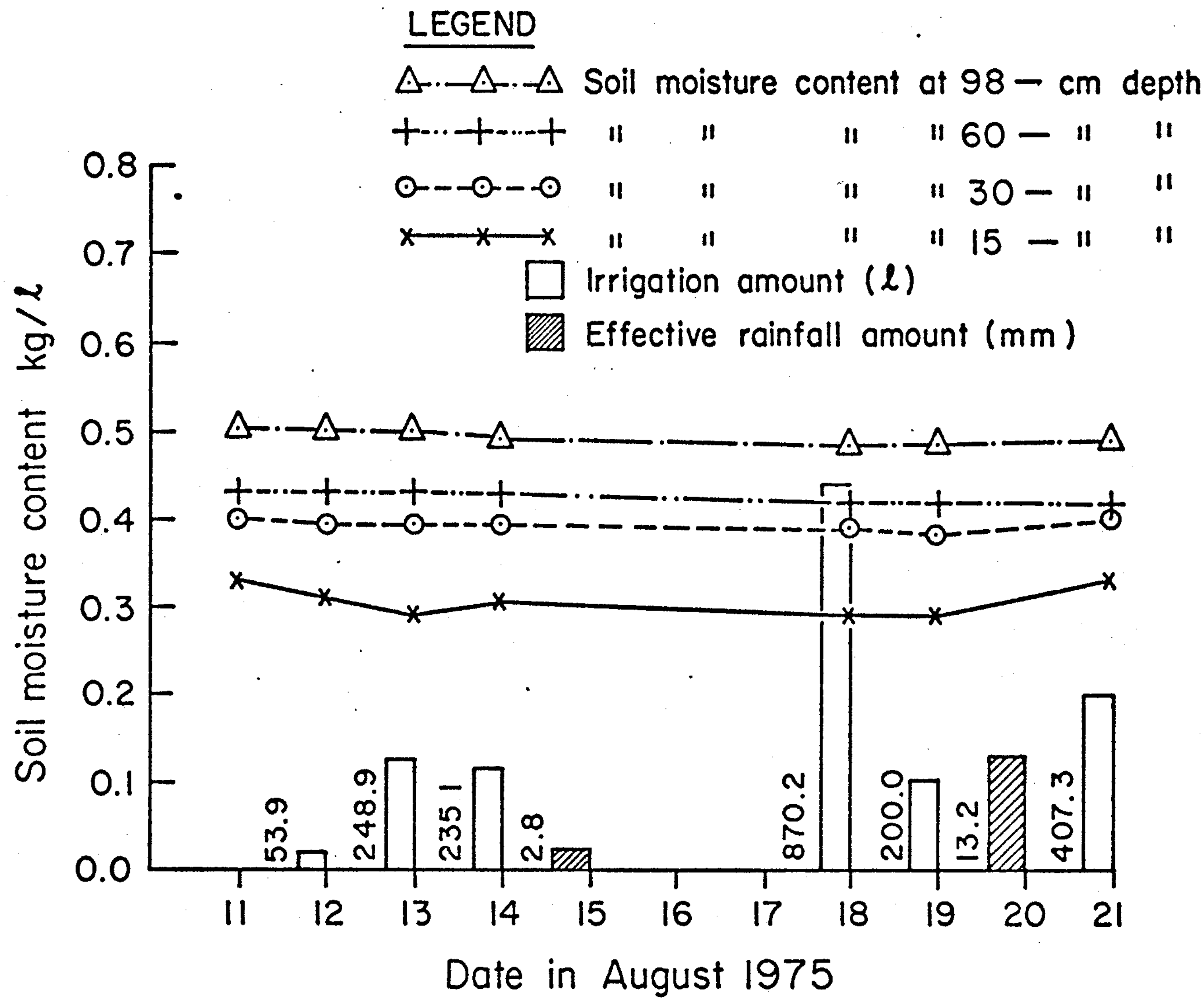


Fig. 5.16 Moisture profile for access tube B I, in the non-irrigated croprow (subsurface)

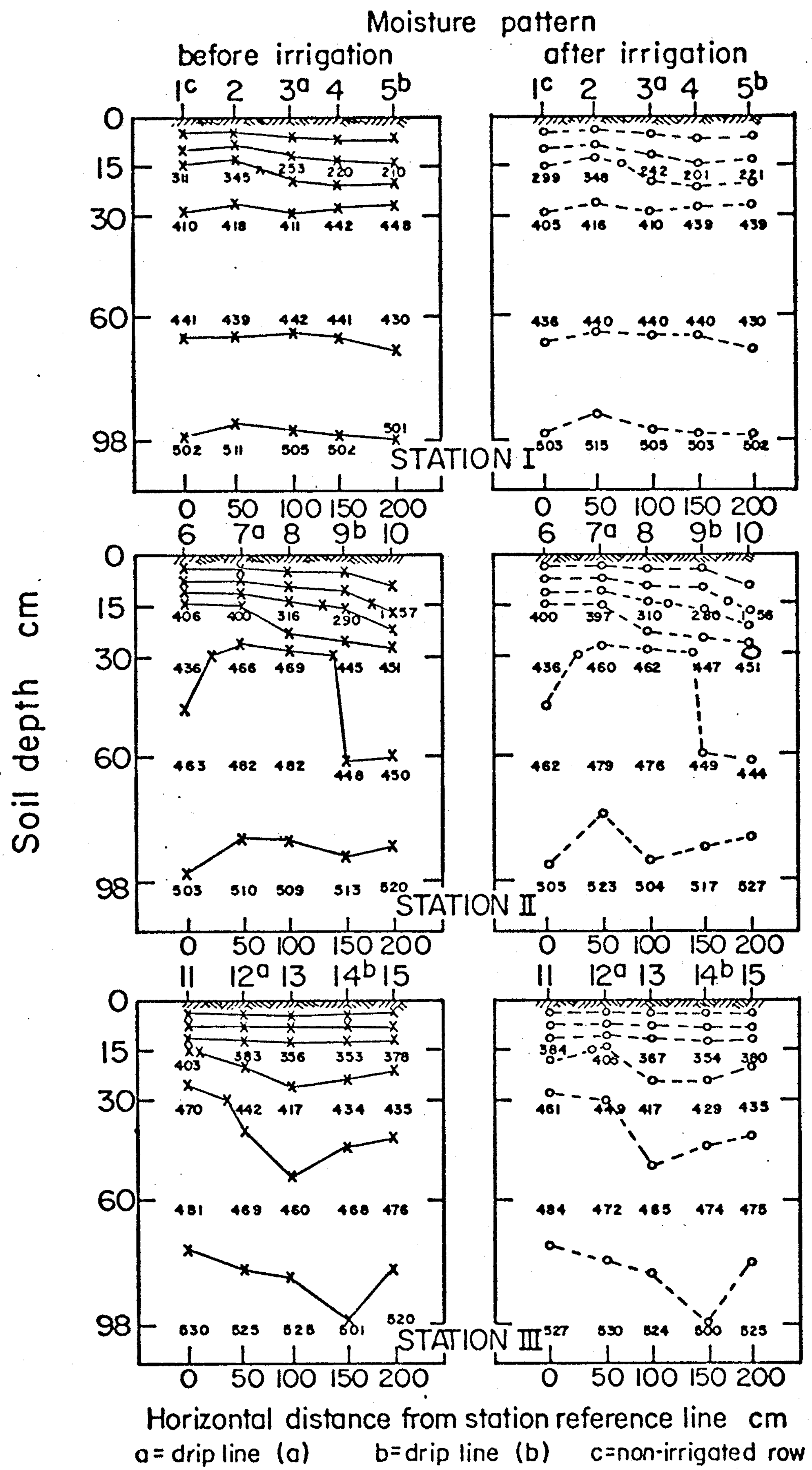


Fig. 5.17 Moisture distribution patterns before and after one day of continuous irrigation (subsurface)

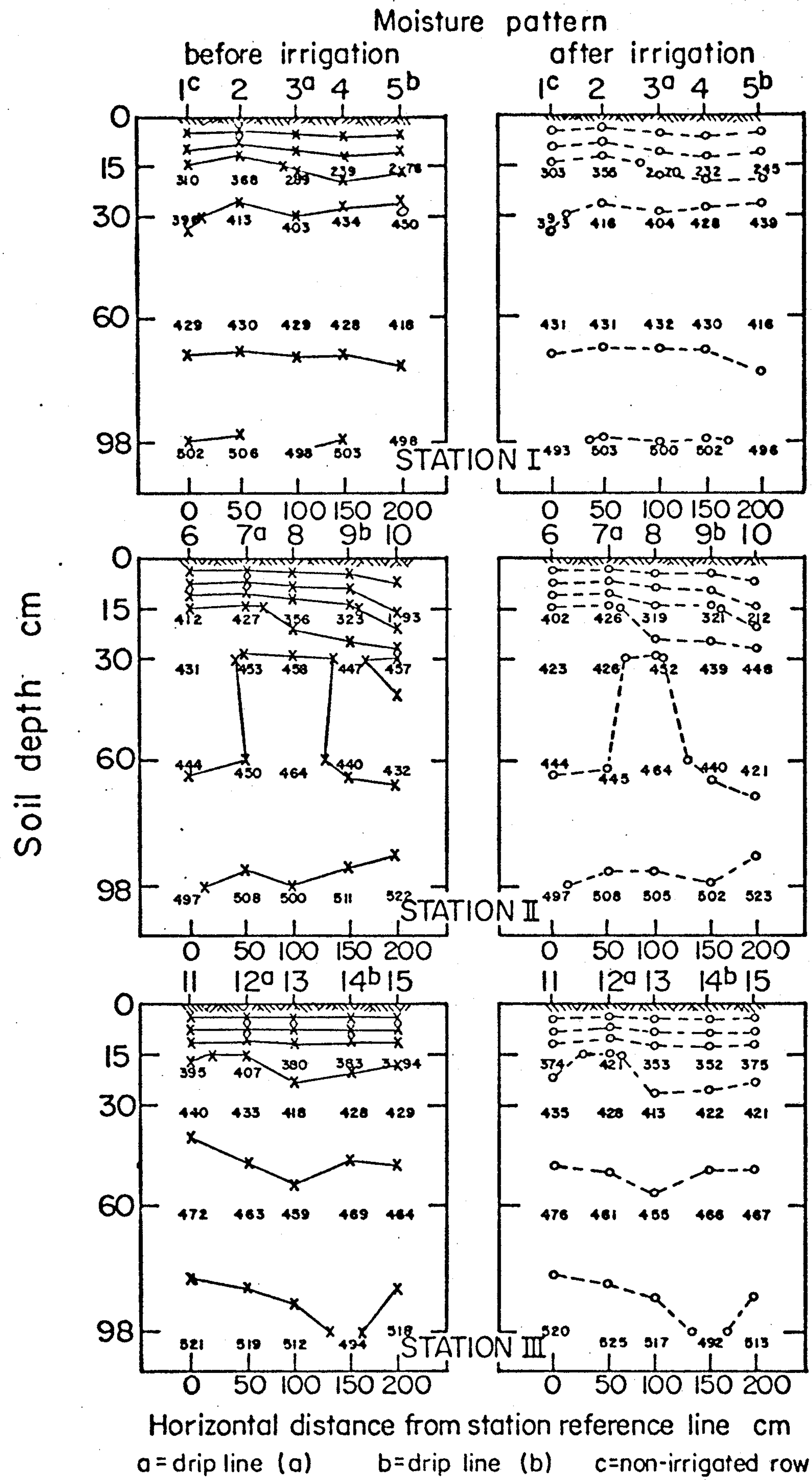


Fig. 5.18 Moisture distribution patterns before and after two days of continuous irrigation (subsurface)

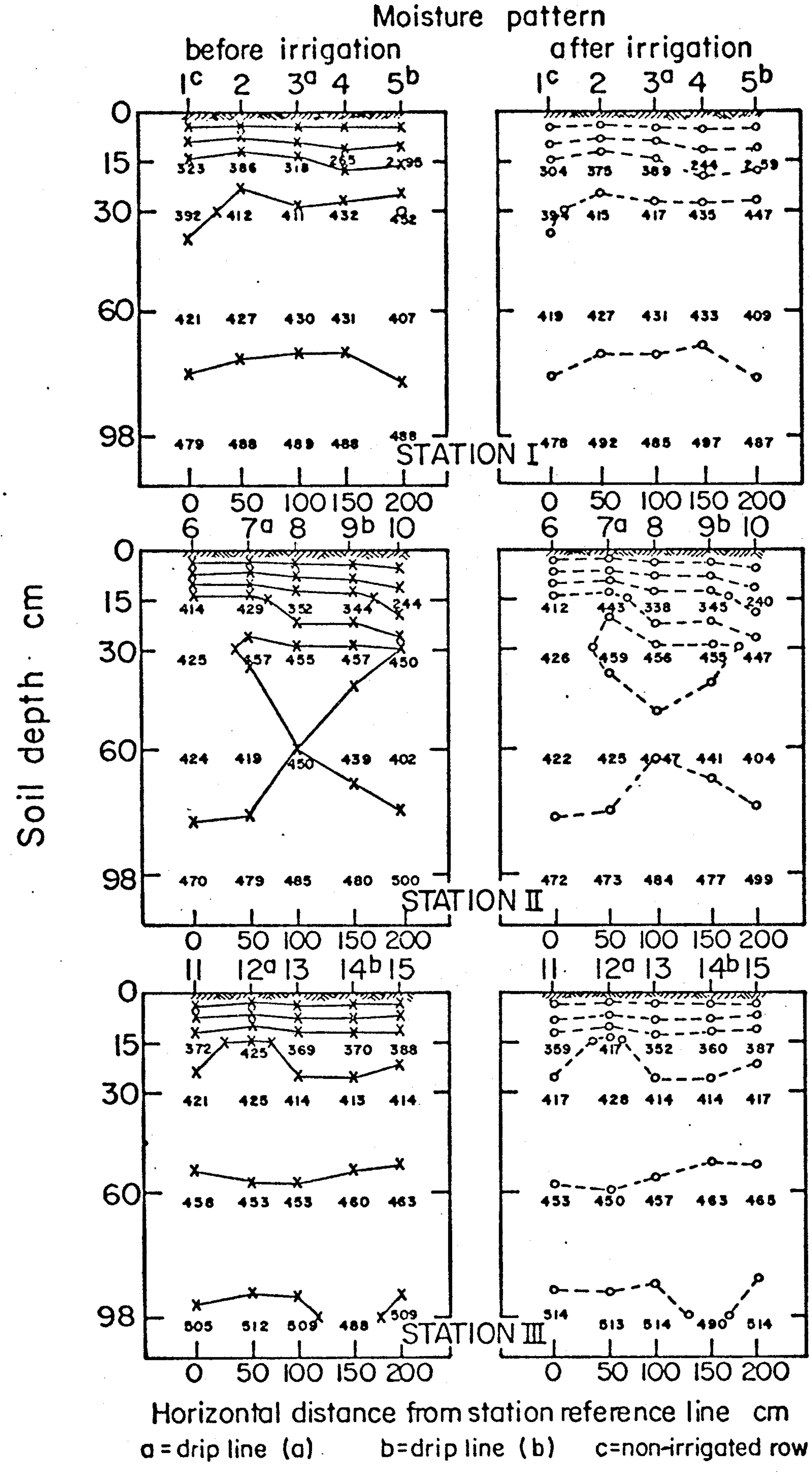


Fig. 5.19 Moisture distribution patterns before and after four days of continuous irrigation (subsurface)

depths in station II (Table 5.15).

5.2.5 Rainfall Contribution Within the Experimental Period

Within the experimental period, May 20 to September 9, the total rainfall was 327.6 mm (12.9-in). All rainfall less than 2.5 mm (0.1-in.) was considered ineffective and probably did not significantly affect the soil moisture conditions. Total effective rainfall was thus 304.8 mm (12-in). To account for evaporation, the total effective rainfall was further reduced to 273.8 mm (10.8-in).

A water surplus of 105.6 mm (4.2-in) occurred in June but was later followed by a 138.9-mm (5.5-in) water deficit in July (Table 5.16). The runoff after a 60-mm (2.37-in) rainfall which fell on June 22, caused serious erosion on both the surface and subsurface drip irrigation systems.

The seasonal water deficit curve (75-percent probability), for the growing season for the five-year period 1971 to 1975, indicated that a monthly water deficit of 127 m (5-in) was possible (Fig. 5.20).

5.2.6 Tensiometer Readings

Within the experimental period, tensiometer readings indicated that the available moisture content at almost all times was never less than 50 percent. Crops therefore suffered no moisture stress.

5.3 Crop Response

Equal yields were recorded on both the surface and subsurface treatments. Total yield per 100-m row length was highest for the furrow irrigation. The water use efficiency and the relative yield percentages were higher for both the surface and subsurface systems (Table 5.17).

Table 5.15 Moisture Contents (g/ℓ) Before and After Irrigation (Furrow)

Access Tubes	Station	First Irrigation Period: Soil Depth (cm) 15	30	60	98	Second Irrigation Period: Soil Depth (cm) 15	30	60	98
1	I	(242) 317	(397) 486	(451) 484	(502) 586	(412) 424	(452) 453	(440) 438	(493) 492
2(a)		(381) 510	(474) 547	(542) 557	(553) 589	(455) 504	(482) 519	(516) 534	(544) 554
3		(280) 447	(382) 491	(416) 497	(501) 599	(420) 467	(429) 474	(425) 443	(505) 505
4(b)		(132) 338	(377) 519	(469) 550	(498) 589	(260) 384	(442) 514	(467) 512	(489) 545
5		(296) 456	(407) 524	(476) 585	(496) 603	(442) 473	(455) 499	(478) 504	(496) 508
6(c)	II	(263) 258	(430) 442	(501) 501	(520) 526	(436) 452	(481) 482	(492) 493	(520) 515
7		(338) 474	(459) 497	(455) 468	(497) 574	(454) 467	(465) 480	(453) 455	(495) 494
8(a)		(208) 354	(464) 528	(495) 533	(502) 558	(359) 419	(492) 514	(496) 507	(500) 547
9		(270) 462	(457) 515	(487) 504	(493) 586	(388) 448	(460) 498	(482) 487	(492) 492
10(b)		(168) 340	(434) 509	(501) 518	(508) 570	(324) 401	(466) 508	(498) 512	(504) 510

( ) moisture before irrigation
(a) tubes along furrow (a)
(b) tubes along furrow (b)
(c) tubes on non-irrigated furrow

Table 5.16 Seasonal Water Deficit (1971-1975 Growing Season) for Glenlea Research Station

	a[1]	b[4]	c 0.9x(b)	d	e 0.75x(d)	f (e-c)	g (c-e)
Period	Total rainfall (in)	Total effective rainfall (in)	Reduced rainfall (in)	Total pan evaporation (in)	ET=0.75 pan	Water deficit (in)	Water surplus (in)
May/74	6.35	5.98	5.38	5.18	3.88	----	1.50
June/74	0.90	0.70	0.62	10.42	7.81	7.18	
July/74	1.41	1.28	1.15	10.82	8.11	6.96	
August/74	2.50	2.28	2.05	7.07	5.30	3.25	
Sept/74	1.26	1.21	1.09	4.35[2,3]	3.26	2.17	
May/73	2.30	2.20	1.98	6.70[2]	5.09	3.11	
June/73	2.87	2.73	2.45	6.94	5.20	2.75	
July/73	5.37	5.30	4.77	7.49[2]	5.61	0.84	
August/73	1.62	1.50	1.35	7.96	5.97	4.62	
Sept/73	2.70	2.37	2.13	5.24[2]	3.93	1.80	
May/72	1.19	1.19	1.07	7.20	5.40	4.33	
June/72	2.44	2.37	2.13	9.13	6.84	4.71	
July/72	1.24	1.21	1.09	7.58	5.68	4.59	
August/72	1.94	1.91	1.71	7.48	5.61	3.90	
Sept/72	3.56	3.23	2.90	5.61	4.20	1.30	
May/71	1.13[2]	1.09	0.98	8.48	6.36	5.38	
June/71	2.08	1.86	1.87	6.85	5.13	3.46	
July/71	3.28	3.10	2.79	7.22[2]	5.41	2.62	
August/71	1.32	1.22	1.09	8.19	6.14	5.05	
Sept./71	2.68	2.45	2.20	4.39	3.29	1.09	
Experimental Period 15th May - 9th September 1975							
May/75	0.36	0.23	0.20	2.29	1.72	1.52	
June/75	8.27	8.22	7.40	4.32	3.24	----	4.16
July/75	1.93	1.51	1.36	9.09	6.81	5.47	
August/75	1.92	1.64	1.48	5.47	4.10	2.62	
Sept/75	0.43	0.40	0.36	2.19	1.17	1.41	

[1]Data extracted from the Monthly Record Metoerological Observations in Canada. Glenlea Research Station
[2]Value based on some estimated daily values.
[3]Data for one or more days missing.
[4]All rain above 0.1" considered effective (28)

Table 5.17 Crop Yield, Relative Yield Percentage and Water Use Efficiency

Irrigation method	Total yield (green wt)[1] (kg)	Yield for 50 random selected cobs (kg)	Yield per 100-m row length (kg)	Total irrigation amount (ℓ)	Applied water per 100-m row length[2]	Water use efficiency (kg/ℓ)	Relative yield % of furrow[3]
Surface	625.95	11.43	114.09	4253.9	775.35	0.147	105
Subsurface	625.95	10.97	114.09	4734.5	862.93	0.132	101
Furrow	408.23	10.88	141.10	4966.3	1716.66	0.082	100
Non-irrigated	381.00	8.30	69.44	------	-------	-----	76

[1]Cobs, stalks and leaves.
[2]Calculated on the assumption of a uniform water application along the rows.
[3]Furrow yields taken as an index of 100, relative yield % was randomly picked cleaned cobs.

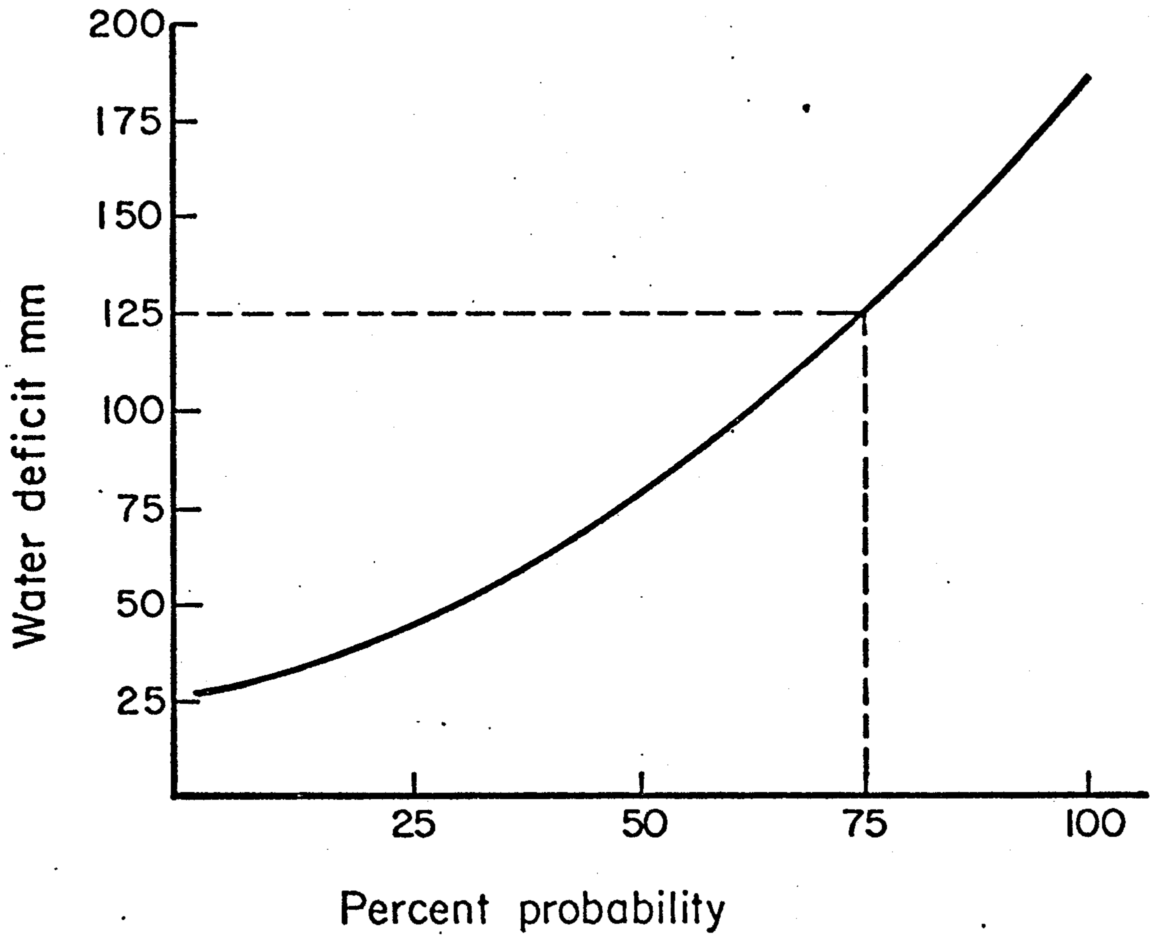


Fig. 5.20 Seasonal water deficit (75% probability) curve, for the growing seasons (1971-1975)

Yield results are considered to have been significantly affected by the reported erosion, non-uniform stands and weeds. In fact, over a considerable number of crop row lengths, practically no germination occurred with the buried system and the surface system. This was due to the seeds being accidentally buried too deep when the drip lines were installed. Also, over a considerable row length, some surface drip lines applied no water along some sections of the rows. The seams of the drip lines folded up, creating water channels. Water from the drip line body flowed along the channels until it reached a depression. Water then dropped to the row, leaving some sections dry and over-irrigating others.

Other observations made in the field were:

i) Viaflo was susceptible to mechanical injury. Unobserved injuries caused spot waterlogging problems and crop loss,

ii) the soil surrounding the buried lines behaved like a sponge readily absorbing water from the drip-line body,

iii) the surface drip lines deteriorated considerably due to algal growth and ultraviolet degradation,

iv) weeds, nonuniform crop stand and the stage of crop development significantly affected the soil moisture content, and

v) over 50 percent of the crops under the surface trickle irrigation system, lodged considerably. The extent of damage which strong winds would cause to the lodged crops was not determined. Also, the extent of loss due to mechanical harvesting of such lodged crops was not determined.

CHAPTER VI

CONCLUSIONS

The results of the investigation to determined the suitability of the high-frequency porous tubing, Viaflo, for the irrigation of row crops, enabled some conclusions to be drawn . They are as follows:

i) the Viaflo laboratory characteristics varied significantly, even for samples from the same Viaflo batch,

ii) a critical operating pressure at which previously unused Viaflo samples failed physically was found to be 4.75 m average. By slowly increasing the operating pressure over an extended period, the Viaflo material would stand pressures above this critical value and a linear correlation between operating pressure and discharge would exist,

iii) no significant correlations were found to exist between the laboratory and the field results,

iv) on the assumption of uniform water application, the buried system showed a superior performance over the surface system,

v) Viaflo was susceptible to mechanical injuries,

vi) the surface system showed a nonuniform water application due to the seams folding up, evaporation and topography,

vii) the surface system drip lines deteriorated to the extent that they tore easily like paper,

viii) higher yield and more uniform crop growth were found for the furrow,

ix) higher relative yield percentages and significant water savings were found for the trickle irrigation systems,

x) trickle irrigation failed in controlling weed growth; rainfall kept weeds alive,

xi) trickle irrigation system output matched both the soil and crop use; at lower soil depths (over 60-cm), continuous irrigation did not affect the moisture levels significantly,

xii) the use of 25-micron filters to provide adequate filtration of irrigation water obtained from a dugout was an inadequate design,

xiii) in the field, drip-line discharge was high initially but stabilized considerably with time, and

xiv) crops under trickle irrigation suffered no appreciable moisture stress.

CHAPTER VII

RECOMMENDATIONS

Recommendations of Viaflo for large-scale irrigation of shallow-rooted crops, appear premature yet. More studies and experience with Viaflo are necessary to establish more useful relationships. The areas suggested for further studies are:

(i) provision of more efficient filtration of irrigation water froma dug out. A sediment tank and a back-flushing or replaceable-type sand filter followed by a 25-micron filter, should be tested. Flush valves would be useful at the drip-line terminals. The pump suction pipe could be mounted on a raft with legs to prevent the pipe from being too close to the dugout bottom,

ii) possibility of fertilizer application with the irrigation water. This would involve investigation of the possible chemical reactions of common fertilizers and irrigation water of various chemical contents,

iii) adoption of farm practises which reduce possible damage to drip lines,

iv) review of the design assumptions under arid conditions, for applicability to Manitoba conditions. Water use, crop-rooting and salt distribution patterns, should be studied, and

v) investigation of the approximate life expectancy of Viaflo would be useful in an economic appraisal of trickle irrigation systems.

Continuous or more frequent irrigation has been shown to contribute to high moisture conditions at lower depths. It is feared that the soil might soon lose its ability to provide an adequate sink to handle snow melt and spring runoff. The effects of continuous irrigation on drainage should be investigated. Also, the leaching potentials of snow melt and spring runoff need investigation.

However, to gain experience and understanding, Viaflo should yet be used on a small-scale. It is recommended that:

vi) due to the variance of operational characteristics, trickle irrigation systems should be evaluated independently. At present, irrigation scheduling are based on the system's in situ (field) performance characteristics, soil type, rainfall and crop use,

vii) a buried system has a longer life expectancy than a surface system. It is also expected to perform more efficiently. Shallow burial of drip lines is recommended for shallow-rooted crops. This way, moisture would always be within the vicinity of the effective root zone. The system performance could be visible; a surface ponding would indicate drip-line injury; a continuous wetted strip would indicate an undisturbed water application, and

viii) disposable type of Viaflo material would eliminate the labor involved in packing and storing used Viaflo drip lines.

Finally, automation appears to have a practical application only when enough experience and understanding of Viaflo is acquired.

REFERENCES

(1) Aljibury, F.K., A.W. Marsha and J. Huntamer. 1974. Water use with drip irrigation. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 341-345.

(2) Bergman, R.C., P.G. Mackauf and R.B. Duggins. 1974. DuPont Viaflo porous plastic irrigation tubing. DuPont De Nemours Inc., U.S. pp. 3.

(3) Berstein, L. and L.E. Francois. 1973. Comparisons of drip, furrow and sprinkler irrigation. J.A. Soc. Agron. 35:796-810.

(4) Bester, D.H. 1974. Drip irrigation on citrus. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 58-64.

(5) Busch, C.D. and N.R. Kneebone. 1966. Subsurface irrigation with perforated plastic pipe. Trans. ASAE, pp. 100-101.

(6) Chapin, R.D. 1973. 99 questions and answers on drip irrigation for row crops. Chapin Watermatics Inc., pp. 1.

(7) Cliff Faulknor. 1973. A little water goes a long way. Country Guide, pp. 20.

(8) Dalton, S.H. and J.M. Myers. 1974. Drip irrigation design criteria for humid regions. Proc. Second International Drip Irrigation Congress. San Diego, California, July, 1974, pp. 33-37.

(9) Deshmukh, M.T. 1974. Development and scope of drip and subsurface irrigation. Proc. Second. International Drip Irrigation Congress. San Diego, California, July 1974, pp. 52-57.

(10) Edminster, T.W. 1974. Time of transition. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 6-8.

(11) Eldon, G.H. and T.C. Patterson. 1974. Vegetable production and water use efficiency as influenced by drip, sprinkler, subsurface and furrow irrigation methods. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 97-102.

(12) Ehezer, Y. and Y. Choresh. 1974. Drip irrigation in citrus orchard 1967-1973. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 456-461.

(13) Ernest, R. and D. Hillel. 1974. The progress and promises of drip irrigation in Israel. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 23-27.

(14) George, B.A. 1974. Keynote address: Welcome to California. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 10-11.

(15) Gerard, C.J. 1974. Drip and furrow irrigation studies on sugarcane. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 329-331.

(16) Goldberg, S.D. 1971. Modern concepts on irrigation. Paper presented Israel National Committee of the ICID.

(17) Goldberg, S.D. and M. Shmueil. 1970. Drip irrigation - a method used under arid and desert conditions of high water and soil salinity. Trans. ASAE, Vol. 13, No. 1,

(18) Haise, H.H., E.G. Kruse and N.A. Dimick. 1965. Pneumatic valves for automation of irrigation systems. ARS 41-104.

(19) Henry, O. 1971. Brief history of irrigation development. Irrigation and Water Resources Engineering. Edward Arnold Company. London, pp. 1.

(20) Hoare, E.R., K.V. Garzdi and J. Blackwell. 1974. Plant water requirements as related to trickle irrigation. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 323-328.

(21) Humpherys, A.S. 1967. Control structures for automatic surface irrigation systems. Trans. ASAE (10) 21-23, 27.

(22) James Zetzsche and J. Newman. 1966. Subirrigation with plastic pipe. J. ASAE pp. 74-75.

(23) Kenworthy, A.L. 1972. Trickle irrigation...the concepts and guidelines for use. Research report. Farm Science. Michigan State University, pp. 2-3.

(24) Kibbutz and Hatzerim. Drip irrigation - Blass system. Netafim, Israel.

(25) Korven, A.C. 1972. Automation of surface irrigation. Drainage Guide, pp. 6.

(26) Leon, N. and R. Roberts. 1974. Automatic drip irrigation for green house tomato production in West Texas. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 159-164.

(27) Marsh, A.W. and C.D. Gustfson. 1971. Irrigating a drop at a time. Crops and Soils Magazine. pp. 10.

(28) McKenzie, R.C. 1974. Field irrigation trials. 1974 Applied Research Summary. Alberta Dept. of Agric. pp. 31.

(29) Michael, D.F. 1974. Drip irrigation in landscaping and soil erosion control. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 44-45.

(30) Michalyna, W. Report of the detailed soil survey of Glenlea Research Station. pp. 9-10.

(31) Michael, S. 1974. Trickle irrigation. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 91-96.

(32) Milligan, T. 1973. Trickle irrigation - Special issue. Irrigation Age. pp. 7-11.

(33) Wolff, P. 1974. Use of drip irrigation in Germany. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 71-76.

(34) Phene, C.J. 1974. High frequency porous tubing irrigation for water-nutrient management in humid regions. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 166-171.

(35) Phene, C.J., A.J. Hoffman and R.S. Austin. 1973. Controlling automated irrigation with soil matric potential sensor. Trans. ASAE 16:773-776.

(36) Rolston, D.E. and D.L. Hoffman. 1974. Use of glycero phosphate for fertiliztion through trickle irrigation systems. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 416-421.

(37) Sheikh, T. and F.K. Aljibury. 1974. Afforestation with saline water in ABU DHABI. Proc. Second International Drip Irrigation Congress. San Diego, California, July, 1974, pp. 370-371.

(38) Spiess, L.B. 1973. Trickle irrigation projects 1973 report. Alberta Department of Agriculture. pp. 22.

(39) Spiess, L.B. 1974. Trickle irrigation 1974 report. Plot 16b AHRC. Alberta Department of Agriculture. pp. 10.

(40) Spiess, L.B. 1973. Trickle irrigation trials. Alberta Department of Agriculture. pp. 5.

(41) Stegman, E.C. 1975. Multiple field management of centre pivot irrigation systems. Paper presented at the Annual Meeting CSAE, Brandon, Manitoba, July 1975.

(42) Sterling, D. and W.J. Pugh. 1974. Drip irrigation: surface and subsurface compared with sprinkler and furrow. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 109-112.

(43) Stevenson, D.S. 1974. Edaphic micro-tubular.continuous flow irrigation in Canada. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 86-90.

(44) Tom, C. 1973. Interest trickles in for drip irrigation. Progressive Farmer. pp. 30.

(45) Vance, J.E. 1973. System slows water to a trickle, on purpose. Fortworth Star Telegram. p. 7E.

(46) van't woudt, B.D. 1969. Trickle irrigation - a promising second tool for a break through in food production in tropical, subtroptical and desert areas. Water Resources Foundation of Australia, Report No. 20, pp. 1

(47) Willoughby, P. and B. Cockroft. 1974. Changes in root patterns of peach trees under trickle irrigation. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 439-442.

(48) Wynand, J.U. 1974. Some results of a field survey of drip irrigation systems in the Republic of S. Africa. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 65-70.

(49) Anonymous. The Volta River project II. Preparatory Commission report. Appendices.

(50) Anonymous. Forward. Proc. Second International Drip Irrigation Congress. San Diego, California, July 1974, pp. 4.

(51) Anonymous. Viaflo porous plastic tubing. A new DuPont product for drip and subsurface irrigation. DuPont De Nemours Inc. U.S.

APPENDIX

Comparison of the Viaflo Discharge Rates, in the Field and in the Laboratory

In the field, the average discharge rate at 3.3 m operating head was 1.78 ℓ/h/100 m.

In the laboratory, the average discharge rate at 3.3 m operating head was 113.3 ℓ/h/100 m.

The average laboratory rate far exceeded the average field rate.