# APPROVAL SHEET

## Performance of different irrigation equipment

**(Design and performance of lateral lines in drip irrigation system )**

By

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**This thesis for Ph. D. Degree in**

**AGRICULTURAL MECHANIZATION**

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## Contents

# 1. INTRODUCTION

With the increasing world food shortage problems and the limited water resource situation, the irrigation system is increasingly important to the purpose of increasing and stabilizing agricultural production.

The primary reason for irrigating crops is to supplement water available from natural sources of water, such as rainfall, dew, floods, and ground water which seeps into the root zone. Irrigation is needed in areas where water from natural sources is adequate for crop production during only a part of the year or in sufficient is some years and not in others. The amounts and timing of irrigation depend on several factors such as climatic, soil and crop.

When a reliable and suitable supply of water becomes available for agriculture it can result in vast improvements in agricultural production and assure economic returns to the grower. Water management, delivering water to the farms and on the farm itself, is the key to successful irrigation projects. Irrigation in arid areas of the world has two primary objectives: (1) to supply the essential moisture for plant growth, which includes the transport of essential nutrient; and (2) to leach or dilute salts in the soil. Irrigation provides a number of side benefits, such as cooling the soil and atmosphere to create a more favorable environment for plant growth. Irrigation management is often designed to maximize efficiencies and minimize the labor and capital requirements of that particular irrigation system while maintaining a favorable growing environment for the plant.

There are some factors which must be taken into account in the selection of an irrigation system. These factors will vary in importance from location to location and crop to crop. These factors include (a) topography; (b) soil depth, texture, and structure; (c) climate; (d) crop characteristics; (e) size and type of water source; (f) quality of water; (g) depth and quality of ground water; (h) the relative cost of irrigation equipment; (i) land preparation and labor; (j) the cost of credit; and (h) the availability and skill of farm labor.

The purpose of any irrigation system is to convey water from a source to the field and to deliver it to the root zone of the crop. A well-designed and operated system will perform this task while meeting three general requirements: assurance of maximum economic return to the farmer; minimal loss of water during conveyance and application; and maintenance of long-term productivity of the land through prevention of soil erosion, soil salinization, and raising of the ground water table. The principal methods used to apply water to the root zone may conveniently be divided into the following main types:

a) Airborne or sprinkler irrigation techniques;
b) Irrigation based on gravity flow;
c) Trickle irrigation; and special techniques.

Trickle irrigation is small amount of water from small-diameter orifices in plastic tubing located on or immediately below the soil surface. The pressure required for the operation of a trickle system may be lower than that required for sprinkler irrigation. Drip irrigation which irrigates only in the root zone can achieve even better irrigation efficiencies than other systems. Whereas drip irrigation does not irrigate the whole area of the field, the total amount of water applied will be less than other irrigation methods because only a portion of the area is irrigated.

The responsibility of the designer extends beyond the provision of an efficiently functioning mechanical system. Not only must soil and cropping factors be considered during the design, recommendations should be given to the farmer on how best to operate his system, and enough flexibility should be incorporated in the design to accommodate changes in cropping patterns that are liable to occur in the future.

The objective of this research is to estimate water and friction head losses and design the lateral lines in a drip irrigation system for distributing water into the field with an acceptable degree of uniformity under different operating conditions.

# 2. Review

## *2.1 Definitions and adaptability*

Yaron et al (1973) reported that trickle irrigation is based on the discharge of small amounts of water from small diameter orifices in plastic tubings located on or immediately below the soil surface. The pressure required for the operation of a trickle system may be lower than that required for sprinkler irrigation. A low discharge is achieved through the use of tiny outlets and low-pressure heads in the supply line.

Solomon and Keller (1978) said that in trickle irrigation, filtered water is applied directly onto the soil through pressure dissipation devices known as "emitters". As with any irrigation system uniformity and efficiency of water application are of major importance.

Bader (1980) said that irrigation is the controlled application of water to the land in order to meet crop requirements not satisfied by rainfall. It provides one of the greatest possibilities for increasing potential production.

Hillel (1982) said that, trickle or drip irrigation is one of the latest innovations for applying water, and it represents a definite advancement in irrigation technology. It can be defined as the precise, slow application of water in the form of discrete drops, continuous drops, tiny streams, or miniature sprays through mechanical devices calls emitters or applicators located at selected points along water delivery lines.

Dasberg and Eshel (1985) said that in drip (trickle) irrigation water is applied to the soil through emitters at a small operating pressure (20-200 kpa) and at a discharge rate of about 1-10 liter/h. The emitters are designed to be pressure dissipaters and may be of different types.

Clemmens (1987) said the purpose of irrigating is to supply water to plants as needed through replenishment of root-zone moisture storage when natural rainfall is inadequate or poorly distributed. However, it is nearly impossible, and certainly unfeasible, for any irrigation system to supply the same amount of water to all plants within a field. In many cases, yield may be directly related to the uniformity at which water is applied.

Hillel (1987) said that the aim of modern irrigation is to make the best of water in conjunction with all other essential inputs (energy, machinery, labor, fertilizers, pest control) so as to enhance and sustain crop production. Widely varying methods of irrigation are employed toward this end, under different sets of circumstances.

Bresler and Rokuro (1990) said that drip irrigation is defined as the slow application of water to the soil surface as discrete or continuous drops. Water is applied to the soil through emitters at a relatively low operating pressure (20-200 kpa) and a discharge rate of about 1-16 l/h.

Keller et al(1990) said that a trickle irrigation system discharges water close to each plant, travel over the soil surface or through the air is of limited importance for distributing the water. The application uniformity basically depends on the uniformity of discharge from the emission devices (emitters). Thus, the design strategy for trickle irrigation system focuses on achieving the desired emission uniformity.

*2.2 Management and scheduling of irrigation*

Amir et al(1980) reported that many factors affect the construction of the irrigation schedule; most of them are unforeseen and, thus, require a rapid response and frequent change. In the construction of an irrigation time-table the planner has to consider these factors and to meet, at every point in time, the crop-water demands and the hydraulic constraints imposed by the network. In addition, weather, pump failures and other unforeseen interruptions introduce a considerable uncertainty requiring rapid response and frequent changes.

Hill and Keller (1980) said, because of the many interactions between scheduling of irrigation water and crop yield, the design of an irrigation system and its subsequent management have a strong influence on net farm income.

Hillel (1983) reported that many factors influence the decision-making process of determining when to apply irrigation water. Among them are climatic setting (arid, semiarid, etc.), water supply (constraints on availability), crop (flowering habit, harvest index, stress sensitivity of the current stage), irrigation system (degree of mechanization and control over application rate amount), soils (profile textures, spatial variability), weather (current and short-term expected), and economics (profit-maximizing level of irrigation). Additional considerations may include electric load management, salinity control, crop quality at harvest, and the cultural or labor scheduling aspects of farming operations.

Eduardo et al(1986) indicated that in the design of irrigation methods, a criterion should be selected that permits the irrigation schedule of the crop in a particular field to be determined beforehand on the basis of historical data. That excludes plant or soil indicator approaches. The criterion used in this investigation to determine the irrigation schedule was the meteorological approach, which requires knowledge of : (1) the physical characteristics of the soil; (2) allowable soil water depletion until the next irrigation; (3) the dynamics of rooting depth; and (4) the evapotranspiration rate of the crop at various stages between planting and maturity.

Richard (1986) developed a linear-programming (LP) framework with an associated design and cost-estimating procedure to evaluate the economics of deficit irrigation in system design and to optimize the sizing and operation of irrigation system components. He found that application to the study area in Idaho indicated that, for a full water supply, system profitability is highest when most deficits are minimized, even though irrigation development may be uneconomic even under a full water supply. The LP model does indicate the most profitable water allocation schedule and system component sizes when a development is confronted with a less than full water supply. A saving in system costs with a full water supply resulted when the role of soil moisture in reducing peak system requirements was considered.

Wu and Irudayaraj (1987) said that the determination of drip irrigation schedule is based on the water requirement of the crop, the output of the drip irrigation system, the allowable deficit condition and the irrigation application efficiency.

### *2.3 Irrigation systems*

Bader (1980) indicated that there are four methods of a applying irrigation water, namely:

1- Surface irrigation (flooding and through furrows);
2- Sprinkler irrigation;
3- Subirrigation;

4- Drip irrigation.

Eduardo et al(1985) presented the procedure to select an optimun irrigation method for specified field conditions. The procedure is develope on the basis of indices that show the acceptability of the irrigation method to the selection parameters (crop density, type of sowing or planting, slop of the field, infiltration rate of the soil, etc.), cost, and financial feasibility The procedure for selecting irrigation methods consists of two steps: (1 Analytical-technical; and (2) technical-economic. Figure (2-1) shows a flov chart of the selection procedure.

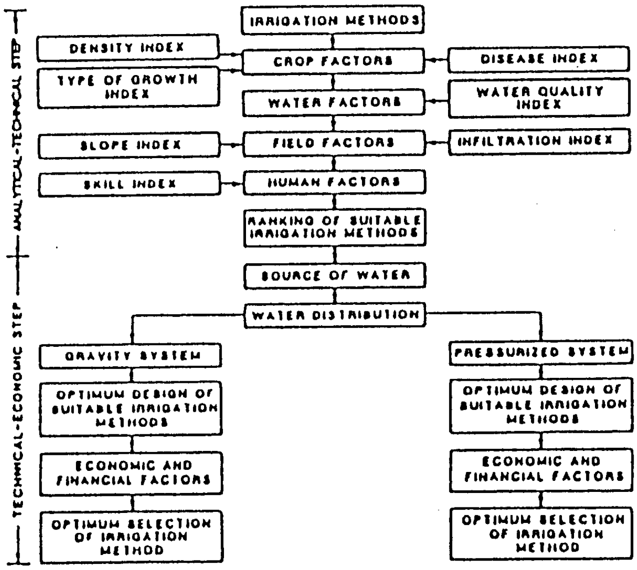


Fig.(2-1): Flow chart for selecting irrigation methods (Eduardo et al, 1985)

Hillel (1983) summarized the factors which are affecting on th selection of appropriate irrigation methods in the table(2-1):

Hillel (1987) indicated that there are, in principle, three main ways t apply water to plants: (1) run the water over the surface of the soil an allow it to infiltrate, a method known as surface irrigation; (2) spray th water into air and allow it to fall onto plants and soil as simulated rainfall a method called sprinkle irrigation; and (3) apply the water directly to the root zone, a method known as drip or sub-irrigation.

ASAE (1989); micro-irrigation is the frequent application of small quantities of water on or below the soil surface as drops, tiny streams or miniature spray through emitters or applicators placed along a water delivery line. Micro-irrigation encompasses a number of methods or concepts; such as:-

1- Bubbler irrigation
2- Drip and trickle irrigation
3- Mist or spray irrigation
4- Subsurface irrigation

Table (2-1): Factors affecting the selection of appropriate irrigation methods (Hillel, 1987).

| Irrig. method | Factors affecting selection | | | | | |
|---|---|---|---|---|---|---|
| | Land | Soil | Crop | Climate | Plusses | Minuses |
| Surface | Level or graded to cntrl slope & surface smooth-ness | Suited for med. to fine textures but not for in-filtra-bility 15mm/hr 1mm/hr | For most crops, except those sensi-tive to standing water or poor aeration | For most climates only slightly affected by wind | Low cost Simple. Low pressure require. | Prone to over-irrigate & rising water-table |
| Sprink. | For all lands | For most soils | For most crops, except sensit. to fung. disease & leaf scorch by salts | Affected by wind (drift, evap. & poor distri-bution) | Control of rate & freq. Allows irrig. sloping & sandy soils | Initial costs & pressure require-ments |
| Drip | For all slopes, regular & ir-regular | For all soils & intake rates | For row crops & orchards but not close-growing crops | Not af-fected by wind. Adapted to all climates | High-freq. & precise irrig. Can use saline water & rough land. Reduced evapor. | Initial & annual costs. Requires expert managmnt Prone to clogging Requires filtra-tion |
| Micro-sprayer | For all lands | For all intake rates | For row crops & orchards | May be affected by wind | High-freq. & precise irrig. Less prone to clog | Initial costs & mainte-nance |
| Bubbler | Flat lands & gentle slopes | For all intake rates | For tree crops | Not affected by wind | High-freq. irrig. No clog-ging. Simple. | Not a commer-cial product. |

Letey et al(1990) classified the irrigation system into gravity flow and pressurized. They said the gravity flow(surface) systems are characterized by water flow in channels across the field. A channel may be a furrow between crop rows, a strip of land bordered by low dikes, or an entire field. The amount and uniformity of water infiltration for gravity flow systems are largely functions of the soil characteristics. Pressurized systems deliver water under pressure through pipes and release it from sprinkler nozzles, small orifices or tubes. Pressurized systems transfer infiltration quantity and uniformity control from the soil characteristics to the design and maintenance of the delivery system. In principle, pressurized systems have the advantage of greater precision on the application amount and location, thereby allowing, in most cases, the potential for greater uniformity of water application than gravity systems. Pressurized irrigation systems, however, initially cost more than gravity flow systems and only through analysis can it be found whether the improved performance from pressurized systems justifies the additional cost.

Plaut et al (1992) reported that the irrigation methods used for cotton include: level basin, furrow, sprinkler, self propelled moving irrigation systems (MSIS) and to a limited extent, drip. The latter method has some advantages over the others and higher yields have been reported with the drip system as compared to others with a similar amount of irrigation water. The MSIS can provide uniform distribution of water and has flexibility with respect to wetting depth. However, its use for cotton raised a serious problem of runoff in some soils.

### *2.4 Advantage of drip irrigation*

Yaron et al (1973) reported that the trickle-irrigation method was developed for the specific conditions of an intensive irrigated agriculture. Some of the technical and agronomical objectives in selecting the optimal irrigation method for such conditions are listed below.

1) The possibility of obtaining high average values (over time) of soil-water content, or low values of suction, without causing soil aeration problems.
2) Minimizing water-content fluctuations during the irrigation cycle.
3) Avoiding destruction of the soil-surface structure and the development of surface crust.
4) Restricting water supply only to those parts of the soil where water uptake by the root system is the most efficient. Selective wetting of

the soil surface has additional beneficial results, such as reducing water evaporation, limiting the growth of weeds, decreasing the need for weed control, and enabling more convenient pest control.

5) Minimizing the salinity hazard to plants by (a) displacing the salts beyond the efficient root volume, (b) lowering the salt concentration by maintaining high soil-water content, and (c) avoiding the burning of leaves and damage due to salt accumulation on the surface of leaves in contact with irrigation water. A dry foliage may retard the development of leaf diseases that require humidity and does not necessitate the removal of plant-protecting chemicals from the leaves by washing.
6) Optimizing the nutritional balance of the root zone by directly supplying nutrients to the most efficient part of the root zone.
7) Saving water by (a) minimizing evaporation from the soil surface, (b) reducing runoff in low permeable or crusted soil, (c) contour cultivation on slope hills, and (d) preventing water loss beyond the borders or the irrigated field by wind confection.

Bucks et al (1981) reported that irrigated agriculture in the future will require farther improvement of existing methods and practices for increasing crop production and conserving energy and water. Trickle irrigation is one method of conserving both energy and water. They said also that multiple cropping and minimum cultivation with subsurface trickle irrigation have several practical advantages over surface trickle irrigation. These include minimal interference with field operations, continuous production of two or more row crops without removal or replacement of trickle lines, and extension of the useful life of a trickle system over a larger production base.

Hillel (1982) summarized the potential advantages of trickle irrigation compared to the other methods as follows:-

a. Increased beneficial use of available water;
b. Enhanced plant growth and yield;
c. Reduced salinity hazard to plants;
d. Improved fertilizer and other chemical applications;
e. Limited weed growth;
f. Reduced labor operation;
g. Decreased energy requirements;
h. Improved cultural practices.

Jam (1988) said that trickle irrigation is the frequent, slow application of water either directly into the land surface or into the root zone of the crop. It has many desirable features. Higher yield, improved crop quality, and reduced water and energy use have all been attributed to trickle irrigation.

Bresler and Rokuro (1990) indicated that there are many advantages for drip irrigation as follows:-

a. Control of water application,
b. Maintenance of high and uniform soil water potential in root zone to improve plant growth,
c. Partial soil wetting,
d. Maintaining dry foliage,
e. Use of low-quality water and reduced salinity hazard to plant,
f. Economic and energy benefits,
g. Fertilizer, herbicide and pesticide application,
h. Adaptation to marginal soils.

Hernandez et al (1991) reported that trickle irrigation has expanded dramatically during the last decade due to increased productivity and greater water and nutrient savings. The high labor requirement in spreading collecting laterals every season, and deterioration of exposed drip lines limit further expansion. Subsurface location of trickles may solve these problems. Furthermore, it may have some plant-related advantages over surface drip irrigation: (i) introduction of nutrients to the center of the root system, where water content is relatively high and steady with time, (ii) reduction in water evaporation from the soil surface, thereby leaving more water available to the plant, and (iii) movement of nutrients in a spherical volume around the emitter, while in surface application transport is restricted to a hemisphere below the point source.

### *2.5 Mechanisms of drip and sprinkler irrigation*

Dasberg and Eshel (1985) classified the drip system components as follows:

#### 2.5.1 Emitters

The emitter is the main component of the drip irrigation system, determining its characteristics. Many types of emitters exist on the market, each with its specific properties. Some of the different types are shown in Fig.(2-2). They may be classified according to the following criteria:

1. Flow rate or discharge and its variation,
2. Form of pressure dissipation,
3. Lateral connection,
4. Cleaning and pressure compensation,
5. Flow regime, and
6. Temperature dependence.

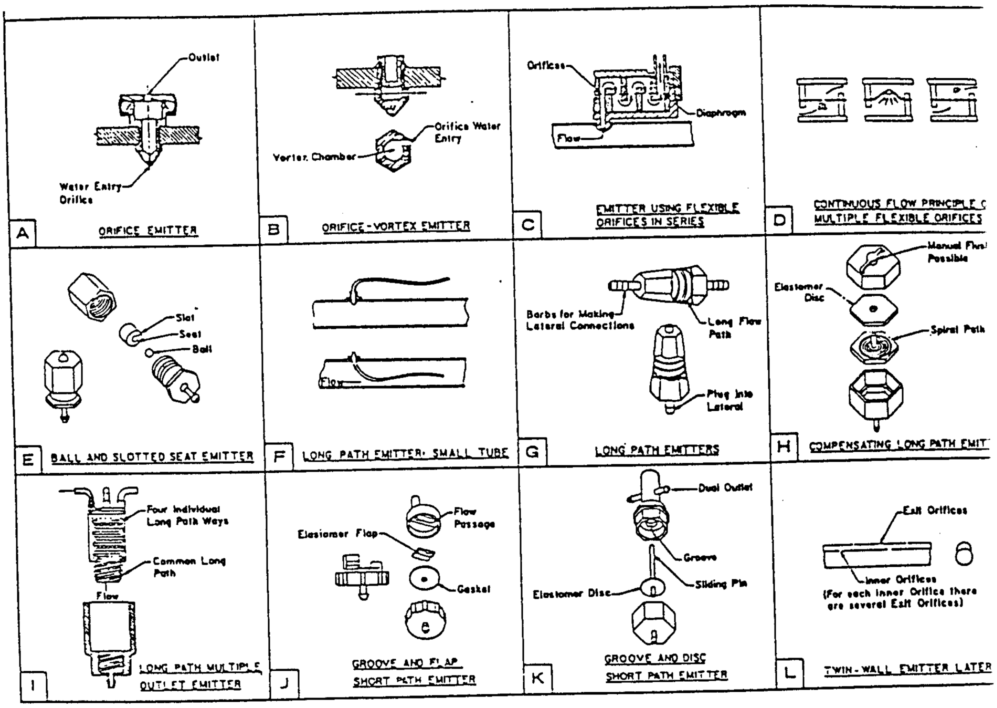


Fig. (2-2): Sketches of some types of emission devices (Dasberg and Eshel, 1985).

### 2.5.2 Laterals

Laterals are the tubes to which the emitters are connected. They are usually made of polyethylene with the following features: flexibility, noncorrosivity, resistance to solar radiation and to the effect of temperature fluctuations, and ease of manipulation. PVC may also be used. Laterals usually have inner diameters of 12-32 mm, and wall thickness made to withstand a pressure of 4-6 atm, depending on need.

### 2.5.3 Submains and Mains

The main and submain lines are usually placed underground and supply water to the laterals. They are normally made of rigid plastic (polyethylene or PVC) in order to minimize corrosion and clogging.

### 2.5.4 Filters

The filter is an essential part of the drip system, its aim being to minimize or prevent emitter clogging. The type of filtration needed depends on water quality and on emitter type. Each type of filter is effective for a particular particle size and type of suspended material, for a specific flow rate, and has a characteristic capacity of sediment collection.

1. Centrifugal sand separators (vortex filters or cyclonic separators)
2. Gravel filters, and
3. Screen filters.

### 2.5.5 Fertilizing system

The fertilizing systems used to add chemicals (nutrients, herbicides or pesticides) to the irrigation water are an important part of the drip system. The process of adding fertilizer to the irrigation water is called “fertigation”. Several methods of fertigation are available.

1. Venturi tube principle,
2. Fertilizer tank (by-pass system),
3. Injection system.

Figure (2-3) shows the components of typical trickle irrigation systems. Water is pumped into most systems and flows through valves, filters, mainlines, submains or manifold lines, and laterals before it is discharged into the field through point-source emitters, bubblers, or micro sprinklers (Jam, 1988).

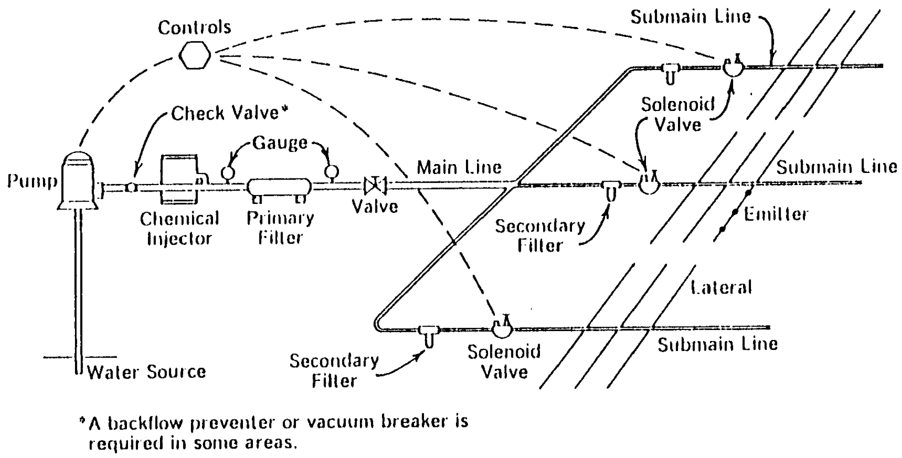


Fig.(2-3): The components of a trickle irrigation system (Jam, 1988).

Bresler and Rokuro (1990) proposed that the basic components of a drip system are: emitters, water distribution lines (i.e. main, submain and laterals), filters, fertilizing (chemigation) injection system, control unit, monitoring components and a pump.

### *2.6 Evaluation of irrigation system*

Keller and karmeli (1974) have suggested two parameters to define the uniformity of application of a trickle irrigation system. Their emission uniformity, $EU$, involves the relationship between minimum and average emitter discharge rates within the system. They noted that this relationship is the most important factor in uniformity of application since a primary objective of irrigation system design is to ensure enough system capacity to adequately irrigate the least watered area. They used $EU$ in the design procedures as an efficiency concept for computing the gross irrigation depth, irrigation interval, and required system capacity. They recommended that $EU$'s of 94% or more are desirable, and in no case should the designs $EU$ be blow 90%.

The other uniformity parameter suggested by Keller and Karameli (1974) is the absolute emission uniformity, $EU_a$, which includes the ratio of both the maximum and minimum emitter flow rates to the average emitter flow rate. These parameters are defined as follows:

$$EU = 100\frac{q_n}{q_a}$$

$$EU_a = 100\frac{1}{2}\left(\frac{q_n}{q_a} + \frac{q_a}{q_x}\right)$$

where:

$EU$ = the emission uniformity, as a percentage;
$EU_a$ = the absolute emission uniformity, as a percentage;
$q_n$ = the average of the lowest 1/4 of the emitter flow rate, in gallons per hour (liters per hour );
$q_a$ = the average of all emitter flow rates, in gallons per hour (liters per hour); and
$q_x$ = the average of the highest 1/8 of the emitter flow rates, in gallons per hour (liters per hour)

Wu and Harris (1975) said the flow conditions in the lateral line (or submain) are steady, spatially varied with decreasing discharge in the line. The energy gradient line will not be a straight line but a curve of exponential type. If a given diameter, $D$, is used, the energy drop can be expressed as:

$$\frac{dh}{dl} = -aQ_l^m$$

in which $a$ and $m$ are constants for a given flow condition ($m$=1 for laminar flow, $m$=1.75 for turbulent flow in smooth pipe, and $m$=2 for full turbulent flow); $dh$ = the energy drop for a given length $dl$, and $Q_l$= the discharge at a section of length $l$ measured from the head end.

Roland (1977) said that irrigation systems are designed to give a reasonably uniform water distribution. The surface distribution uniformity of irrigation water is expressed by the Christiansen uniformity coefficient, $CU$. Pipe laterals are designed so that the variation in outflow between individual outlets should not be excessive. In the case of sprinkler systems the allowable variation is usually expressed in terms of the difference in outflow between the first and the last outlets. It expressed by the pressure drop over the lateral length, given as a percentage of the design outlet pressure. In the case of trickle systems the maximum permissible deviation in outflow from that at the average or design outlet is usually specified.

Anon (1978) recognized that the following field distribution terms for on-irrigation are useful for evaluating the ability of an irrigation system to apply water uniformity. As before, the definitions are expressed in equivalent depths of free water.

Distribution Uniformity ($DU$) is the ratio of the average low quarter depth of irrigation water infiltrated to the average depth of irrigation water infiltrated. The average low quarter depth infiltrated is the average of the lowest one-fourth of the measured or estimated values where each value represents an equal area of the field:

$$DU = \frac{\text{Average low quarter of water infiltrated}}{\text{Average depth of water infiltrated}}$$

The $DU$ is a useful indicator of distribution problems. A low $DU$ indicates that excessive deep percolation losses will occur if adequate irrigation is supplied to all areas.

Coefficient of uniformity ($CU$) is the ratio of the average depth of irrigation water infiltrated (or caught) minus the average deviation from this average depth, divided by the average depth infiltrated (or caught). The $CU$ can be expressed as:

$$CU = 1 - \frac{\sum_{i=1}^{N} |x_i - \bar{x}|}{N\bar{x}}$$

in which $\bar{x}$ is the mean of N single observations of water depth infiltrated, $x_i$, where each $x_i$ represents an equal area of the irrigated field.

Terry and Barinas (1980) measured the pressure losses across on-line connected (inserted) trickle emitters, PVC pipe fittings and barbed PE pipe fittings. They said that the pressure loss across fittings has been termed a "minor loss", but since many fittings are used in a trickle irrigation system, these minor losses can become significant. They compared between 40 emitters in one line and added an other 40 emitters to the same line. They found that, the addition of a new emitter at each tree would increase the lateral flow rate from 300 to 600 l/h. The total pressure head loss would increase from 2.76 to 10.51 m. The pressure head loss caused by the emitter connection would increase from a rather insignificant 1.8 percen of the total with 40 emitters to 8.6 percent of the total with 80 emitters.

Wu and Gitlin (1981) studied the different pressure profiles in a single inlet system when a lateral length and operating pressure are fixed at different line slopes (uniform). The pressure profiles can be classified according to a dimensionless ratio ,$\Delta H'/\Delta H$, in which $\Delta H'$ is the energy gain or loss by slope at the end of the line and $\Delta$H is the total energy drop by friction at the end of the line. Fig.(2-4) shows the five possible pressure profiles. They are as follows:

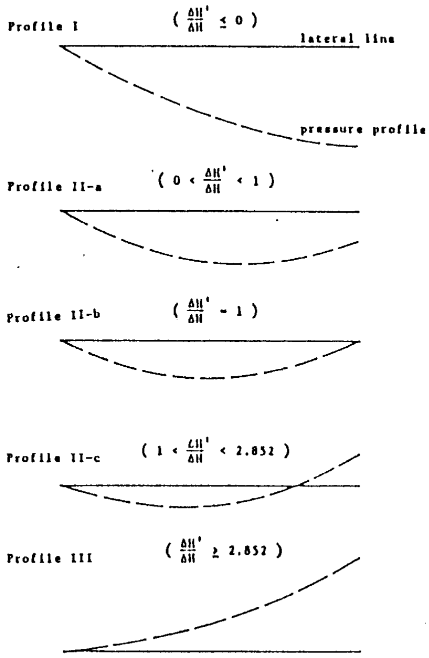


Fig.(2-4): Five Pressure profiles along a lateral line caused by a single inlet system.

Pressure profile type I. The pressure decreases with respect to the lateral length. This occurs when the lateral line is laid on zero or uphill slopes. In this condition the dimensionless ratio $\Delta H'/\Delta H \leq 0$.

Pressure profile type II.
The pressure decreases with respect to the lateral line length, reaches a minimum point and then increases with respect to the lateral line length. This profile can be also classified into three types according to the slope situation:

1 *Type II- a:* This occurs under the slope situation where $\Delta H'/\Delta H$ is larger than zero but less than 1. The pressure at the end of line is less than the operating pressure.

2 *Type II- b:* This occurs under the slope situation where $\Delta H'/\Delta H$ is equal to 1. The pressure at the end of the lateral line is equal to the operating pressure. This type is considered as the optimal profile because it has the minimum pressure difference.

3 *Type II- c:* This occurs under the slope situation where $\Delta H'/\Delta H$ is larger than 1 but less than 2.852. For this condition the pressure at the end of the line is larger than operating pressure. The constant 2.852 is determined as the ratio of the total friction drop at the end of a pipe calculated by using total inlet discharge to the total friction drop, $\Delta H$, at the end of a lateral line, assuming that both have the same total inlet discharge, diameter, length, and the Williams and Hazen equation is used.

Pressure profile type III. The pressure increases with respect to the lateral line length. This is caused by a steep downslope situation where $\Delta H'/\Delta H$ is equal to or larger than 2.852 (the energy gain is larger than friction drop for all sections along the lateral line).

Wu (1983) mentioned that, the design criterion of a drip irrigation lateral line has been based on the uniformity of orifice (or emitter) flow along the line. The orifice (or emitter) flow is controlled by the pressure variation along the lateral line. The pressure variation along the lateral line is determined by energy drop due to friction and energy gain (or loss) due to slope.

Wu and Gitlin (1983) said that the uniformity of emitter ( or orifice ) flow depends on the emitter flow variation along lateral lines which is mainly affected by the hydraulic design of the drip irrigation system, manufacturing variation, temperature, and emitter plugging including partial plugging of emitters.

Walker (1987) described the principal objective of evaluating an irrigation system as being to identify alternatives that may be both effective and feasible in improving the system's performance. For instance, the evaluation may reveal that the application efficiency could be improved by limiting the duration of irrigation. Uniformity may be improved by adjusting the flow rate. Also, it may be discovered that the field length or slope requires modification for the existing system to operate more effectively.

Warrick and Yitayew (1988) indicated that an important objective of any trickle system is a uniform distribution of water delivered through the emitters. Computation of flow distribution requires knowledge of the variables such as pressure, flow rate, length of lateral, characteristics of the orifices, and frictional loss in the system. They said that several studies had been established these relationships. In each study, the primary solution is based on a discharge that is uniform, although ramifications of the manufacturer's variability have been modeled based on the derived hydraulic profile.

Wu (1988) said that the uniformity coefficient in sprinkler irrigation, in fact, should be considered as a significant item of the system since it reflects the pattern of input of water received by the field. The nonuniform pattern of the sprinkler system will result in over irrigation and under irrigation for certain areas in the field. If the irrigation scheduling is made so that the minimum irrigation depth can meet the water requirement, extra irrigation has to be scheduled to compensate for the nonuniform distribution of the system.

ASAE (1989) defined the manufacturer's variation as follow: it is a measure of the variability of discharge of a random sample of a given make, module and size of emitter, as produced by the manufacturer and before any field operation or aging has taken place.

$$CV = \frac{S}{\bar{x}}$$

$$S = \left[ \frac{\sum_{i=1}^{n} \left( x_i - \bar{x} \right)^2}{(n-1)} \right]^{1/2}$$

where:-

$CV$ = manufacturer's variation

$\bar{x}$ = the mean discharge of emitter in the sample

$S$ = the standard deviation of the discharge of the emitter in the sample
$x_i$ = the discharge of an emitter
$n$ = the number of emitters in the sample.

Wu (1992a) said there are several uniformity parameters which can be used as design criteria. The following is a review of several different uniformity definitions.
Emitter flow variation was defined as:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}}$$

where $q_{var}$ is the emitter flow variation, $q_{max}$ and $q_{min}$ are maximum, and minimum emitter flow respectively along a lateral line or in a submain unit.
The uniformity coefficient of emitter flow is determined using the uniformity coefficient equation developed by Christiansen:

$$UCC = 1 - \frac{\Delta\bar{q}}{\bar{q}}$$

$UCC$ is the Christiansen uniformity coefficient, where $\bar{q}$ is the mean emitter flow and $\Delta\bar{q}$ is the mean deviation of emitter flow.

The statistical uniformity is expressed as:

$$UCS = 1 - \frac{S_q}{\bar{q}}$$

where $UCS$ is the statistical uniformity coefficient and $S_q$ is the standard deviation of emitter flow.

Edmar and Allen (1993) derived the friction head losses along the lateral line in uniform and variable outflow condition as follows:

| | uniform | variable |
|---|---|---|
| 1- The flow rate ($Q_s$) at any point in these laterals can be estimated by: | $Q_s = Q_o\left(1-\frac{S}{L}\right)$ | $Q_s = Q_o\left(1-\left(\frac{S}{L}\right)^2\right)$ |
| 2- The friction head loss ($H_{fl}$) in a lateral is: | $H_{fl} = H_{fo} \cdot F$ | $H_{fl} = H_{fo} \cdot F$ |
| 3-The correction coefficient ($F$) factor is: | $F = \frac{1}{(m+1)} + \frac{1}{N} + \frac{(m-1)^{0.5}}{6N^2}$ | $F = \frac{\Gamma(0.5)\Gamma(m+1)}{2\Gamma(m+1.5)}$ |

Where:-

$Q_s$ = flow rate at any distances from the pipe inlet,

$Q_o$ = total flow rate of the lateral,

$L$ = total length of the lateral,

$H_{fo} = \frac{c\,Q_o^m L}{D^n}$ = friction head loss in pipe similar to lateral pipe, conveying total flow in its entire length, L;

$m$ = velocity exponent,

$N$= number of equally spaced operating outlets in the lateral, and

$\Gamma$ = symbol of Gamma function.

Wu (1992a) said a drip irrigation system is a pressurized piping system which consists of a main line, submain and laterals. The pressure variation in the laterals will affect directly the emitter flows in the drip irrigation system. Considering the velocity head in the total energy relation (Bernoulli's equation) is relatively small for drip irrigation lines, the total energy can be simply expressed by:

$$H = z + h$$

where $H$ is the total energy expressed as a height (or head) of water, $z$ is elevation as potential energy and $h$ is pressure head.

Hathoot et al (1993) reported that in trickle-irrigation laterals, emitters are installed at an equal spacing. The emitter discharge depends on the pressure head as given by the following relationship:

$$q_i = c H_i^y$$

where:-

$q_i$ = the discharge of the emitter;

$H_i$ = the pressure head in the lateral pipe at the emitter under consideration;

$c$ = the emitter coefficient that areal and discharge effects; and

$y$ = exponent depending on the type of flow regime, and generally ranges between zero and 1.0.

Nishiyama et al (1993) indicated that micro irrigation includes drip irrigation and micro sprinkler irrigation. It is generally used for high value economic crop production in green houses and small size farms. The length of the lateral line is about 50-70 m or less. Under these conditions, simple hydraulic design methods can be used by assuming a water pressure at the end of the lateral line, so that a step-by-step calculation can be made for all emitters (or micro-jets) along the lateral line from the end point to the inlet of the lateral.

### *2.7 Factors' effect on irrigation system performance*

James and Watts (1977) said that, because irrigation is such a large consumer of the total energy used in production agriculture, reduction of the energy used to pump water can have a significant impact on agriculture's energy requirements. This energy requirement can be lessened by reducing the amount of water pumped, improving the irrigation efficiency, improving the pumping plant performance, and lowering the pressure requirements.

Wu and Gitlin (1977) indicated that, under certain field conditions, the length of lateral and submains may be relatively long and have nonuniform slopes. The lateral and submain design may use a series of different pipe sizes. Their study showed that, if a submain or lateral can be divided into several sections and varying sizes are designed for each section, the energy gradient line of each section is very close to a straight line except for the last section. The study showed that, when the submain or lateral is divided into sections, the mean discharge of each can be used to estimate the total energy drop by friction without causing much error.

Chaudhry (1978) said that the problem of design and operation of overhead or surface irrigation systems that distribute water nonuniformly over the field is presently resolved in two ways. The more widely used approach aims at supplying an adequate average irrigation depth for given soil conditions with reasonably high uniformity characterized by uniformity coefficients that are essentially measures of certain aspects of the dispersion of the depth over the field. The purpose of this approach is to minimize the reduction in crop yield as a consequence of nonuniformity of irrigation. As higher uniformities are usually achieved at greater initial and maintenance costs, systems with lesser uniformity may become economically desirable.

Nakayama et al (1978) said that clogging of emitters or orifices in trickle irrigation systems is a widespread problem that has caused many early users to abandon their installations. Recently, water treatment methods have been applied to irrigation water for improving the performance and reliability of emitters. In all instances, water quality plays the dominant role in the operation of the system, but defining precisely the involvement of the various constituents in the water in clogging is difficult. In general, water with fewer of the following factors appears to create the least problems: (1) Suspended inorganic and organic particulate materials; (2) dissolved chemical constituents that cause scaling, such as calcium carbonate, iron, and manganese oxide; and (3) microbes that cause slime development and agglomeration of suspension, or are involved in biochemical accumulation of heavy metals and sulfides. Any one of the physical, chemical, or biological factors at sufficient levels can be the prime contributor to clogging, but when several of these factors are present simultaneously, the problem can be aggravated almost synergistically.

Solomon et al (1978) indicated that the actual emitter discharge rates vary considerably and depend upon:

1) Designed emitter characteristics;
2) Variability in manufacturing and aging of emitters;
3) Frictional head losses throughout the pipe distribution network;
4) Elevation differences throughout the field;

5) The number of clogged emitters in the system;
6) The number and degree of partially clogged emitters in the system;
7) Variation in the water temperature throughout the system.

Wu and Gitlin (1979) said that a comparison of the energy gradient line (friction) and the line slopes will show the pressure variation. If the line slope matches exactly the energy gradient line, this means there is no pressure variation along the line. If the line does not match exactly with the energy gradient line, this means there are pressure variations along the line. An allowable pressure variation can be set along the energy gradient line and can be drawn as a curve. The area between the energy gradient line and the allowable pressure variation curve can be used for designing drip irrigation lines for both uniform or nonuniform slopes. If the line slope can be put within the area, the design will have a pressure variation less than the set allowable pressure variation. Also, they indicated that if the change of velocity head in a drip irrigation line is small, compared with the potential and pressure heads, it can be neglected. Therefore, the pressure variation along the lateral line can be determined simply by a linear combination of energy drop by friction and energy gained (or lost) by slopes.

Bader (1980) studied the effect of drip and furrow irrigation on cabbage and pea yield. He found that the yield decreased from 11387.6 to 7286.3 Kg/fed. of the cabbage and from 1680 to 714 Kg/fed. of the pea for drip and furrow irrigation respectively.

Terry and Barinas (1980) said that the purpose of the design procedure is to determine the arrangement and size of the system components such that the crop water requirements can be met subject to constraints on labor, water, energy and total investment. They added, an important element in the trickle irrigation design procedures is the determination of pressure losses in the trickle lateral length, pipe size, emitter spacing, ground slope and emitter flow rate which are considered in most design procedures.

Harry and Soom (1981) said that trickle irrigation uses small diameter plastic pipes or tubes with water emission devices at necessary spacing to deliver water to the soil near the plants. The sizing of tubes for a trickle irrigation lateral is based on numerous factors: hydraulic principles, emitter flow characteristics, row length, elevation, equipment and energy cost, and some criterion of water application uniformity which is related to several of the aforementioned factors.

Abd-El-Slam (1985) studied the effect of furrow and drip irrigation systems on weed growth for potato crops. He found that the amount of weeds increased with the increase in the amount of water supply for both irrigation systems. Weed growth in drip irrigation treatments was found to be less than half of that for treatments irrigated by furrow irrigation.

Kyung and Busch (1985) indicated that the irrigation systems should be designed and operated to supply water in a predictable, adequate, and equitable manner so that water is used effectively and efficiently. However, many old irrigation systems do not perform in the best manner because they use excessive water that is inefficiently delivered and applied. Major factors to be considered in system planning include application and delivery system costs and efficiencies, operation and maintenance costs, land and water allocation, and water cost, along with institutional and social constraints. Because of the conflicting trade-offs among these and other factors, it is very time consuming and costly to determine the best system component combinations using conventional planning methods, especially when developing plans for a large area.

Letey (1985) recommended that uniformity of water application within a root zone is important for orchards. Pressurized irrigation systems used on orchards include high volume sprinklers, low volume sprinklers, drip, misters, etc. The uniformity of water distribution is likely to vary considerably for these different systems. Optimization of irrigation requires information on the distribution pattern for individual trees as well as variations in water application between trees. He added that the rooting pattern under nonuniform water application would adjust to accommodate differences in water distribution. However, if the water applied, some deep percolation occurs for the nonuniform case whereas no deep percolation occurs for the uniform case. Therefore under the latter condition the plant growing under the uniform irrigation would be expected to produce more than the plant under the nonuniform irrigation for the same amount of seasonal water application.

Eduardo et al (1986) mentioned that agriculture is the largest consumer of water in the world and its application efficiency is still low. In addition, agriculture is faced with a steadily increasing competition for water and an increasing demand for its products. The design of irrigation methods greatly affects water application efficiency, and involves several variables and restrictions whose aim is maximizing farm profits or minimizing cost.

Schwartzman and Zur (1986) indicated that a drip irrigation is characterized by application of water through low discharge emitters. Soil water flow under drip irrigation could be described as line source, two-dimensional or point source, three-dimensional depending on the distance between emitters along a lateral. When drip irrigation is used for row crops, emitters are spaced in order to produce a continuous strip of wetted soil along the row. The distances between emitters would determine the degree of overlap between neighboring wetted circles. In addition, the cost of a unit length of a lateral is influenced by the number of emitters on it.

Bader (1987) studied the effect of soil moisture distribution and fruit yield in an orange orchard irrigated by drip and mini-sprinkler systems. The data showed that in-line dripper gave a good soil water distribution for the two directions: spacing between trees on the lateral and the soil depth under the zone of lateral. He found that the best water distribution in soil profile under drip system was the system which had two laterals of in-line dripper. Also, the mini-sprinkler system gave the best yield of oranges because the wetted area in this system reached up to 80-85% of the total area and soil moisture distribution was deeper than drip irrigation treatments.

Hassan (1987a) reported that, in the design of drip irrigation system, it is often necessary to select the size (length and width) of subunit and a designed emission uniformity (EUD) before proceeding with expensive design calculations. He found that the optimum size is the size which enables using the smallest lateral size with the maximum length maintaining emission uniformity equal to or more than 90 percent till 10 and 20 percent inflation rate of energy cost for electricity and diesel sources respectively and moves to be with the same lateral size and emission uniformity 95 percent for inflation rate up to 30 percent for both energy source.

Hassan (1987b) studied the effect of dripper discharge rate on distribution of moisture in sandy soils under a drip irrigation system. His results indicated that increasing the dripper discharge rate resulted in an increase in the horizontal component and a decrease in the vertical component of the wetted zone.

Hassan and Younis (1987) indicated that, in the design of a drip irrigation system, it is often necessary to select a designed water velocity before proceeding with extensive design calculations. In general a higher water velocity results in more friction loss. This fact has economic ramifications. They found that the optimum water velocity for laterals ranged from 0.5-1.0 m/s for submain it ranged from 1.0-1.5 m/s, and from 0.5-1.5 m/s for main line. When considering different inflation rates in energy cost the optimum water velocity did not exceed 1.0 m/s for different pipe line categories.

Wu and Irudayaraj (1987) used a computer simulation to determine the emitter flows of about 1500 submain units for different hydraulic and manufacturer's variations. They calculated four uniformity parameters, uniformity coefficient (*UCC*), coefficient of variation (*CV*), pattern efficiency (*PE*) and emitter flow variation for each case. They found that high regression coefficients ($R^2$= 90 - 100%) were obtained for any two of the four uniformity parameters for emitter flow variation caused by hydraulics only or hydraulics with a fixed manufacturer's variation.

Yitayew and Warrick (1987), evaluated the effect of velocity head on the total energy drop. Table (2-2) summarized the lateral head drop without velocity head $\Delta H$ ; the lateral head drop with velocity head included $\Delta H^*$ and the relative error $E = \{1-(\Delta H / \Delta H^*)\}$. They said that, as expected , the magnitude of the total energy drop is found to be greater for turbulent flow compared to laminar flow-irrespective of whether the velocity head is included. However, the relative error in total head loss by neglecting velocity head is higher for laminar flow than for turbulent flow. The implication is in design of trickle laterals; the inlet pressure will be slightly overestimated by neglecting the velocity head. This means more energy is required to maintain the overestimated inlet pressure. Most importantly, the solution is as simple as the conventional approach, and there is no reason not to use the complete solution and avoid overestimating lateral pressure drop.

Table (2-2): Expressions for calculating friction coefficient, total head loss, and fractional decrease when velocity head is included.

| Variable | Laminar ($m = 1$) $Re \le 2000$ (1) | Smooth Pipe ($m = 1.75$)[a] $10^5 < Re \le 10^7$ (2) | Fully turbulent ($m = 1.828$)[b] $Re > 10^7$ (3) |
|---|---|---|---|
| $f_e$[c] | $64\ \nu/D$ | $(0.316)(\nu/D)^{0.25}$ | $0.130\ (\nu/D)^{0.172}$ |
| $\Delta H$(m) | $20.4\nu L^2 q/g\ D^4$ | $(0.0877)\ \nu^{0.25}L^{1.75}q^{1.75}/gD^{4.75}$ | $0.0357\ \nu^{1.172}q^{1.828}L^{1.828}/g\ D^{4.828}$ |
| $\Delta H^*$(m) | $(0.087\nu qL^2/gD^3) - (1.62q^2L^2/D^2)$ | $(0.0877\nu^{0.25}L^{1.75}q^{1.75}/gD^{4.75}) - (1.62q^2L^2/D^2)$ | $(0.0877\nu^{0.172}L^{1.828}q^{1.828}/gD^{4.828}) - (1.62q^2L^2/D^2)$ |
| $1 - \Delta H^*/\Delta H$ | $(0.0398)\ q/\nu$ | $(9.24)\ D^{0.75}q^{0.25}/L^{0.75}\ \nu^{0.25}$ | $22.7\ D^{0.828}\ q^{0.172}/\nu^{0.172}L^{0.828}$ |

[a]Blasius pipe

[b]Water and Keller, 1978.

[c]Units of $\nu$ and $D$ are $m^2s^{-1}$ and m, respectively, to give $f$ in consistent SI units.

According to the ASAE (1988) the water application uniformity is affected by the hydraulic design, topography, operating pressure, pipe size, emitter spacing and emitter discharge variability. The emitter discharge variability is due to water temperature variation, emitter manufacturer's variation, emitter wear and emitter plugging. The coefficient of variation and the statistical uniformity shall be used to evaluate the emitter discharge variation and to differentiate between hydraulic design and emitter performance variation.

Yitayew and Warrick (1988) reported that the design of trickle distribution systems depends upon a good understanding of the lateral hydraulics and emitter characteristics. Hydraulically, trickle irrigation is considered as steady, spatially varied manifold flow with the discharge decreasing along the line from the inlet. With decreasing discharge along the lateral, the energy gradient line depends upon friction, which is a function of velocity in the pipe and cross-sectional area of the pipe, and on the natural slope of the line.

ASAE (1991) reported that the water application uniformity (for nonpressure compensating emitter) is affected by the operating pressure, emitter spacing, land slope, pipeline size, emitter discharge rate and emitter discharge variability. The emitter discharge variability is due to pressure and temperature changes, manufacturing variability, aging and clogging.

El-Berry et al (1989) compared basin, sprinkler and subsurface drip irrigation systems on fodder production in sandy soil in arid land. Their results indicated that subsurface drip irrigation was superior to the other two studied systems. Whereas the fodder yield was increased by about 130% over the sprinkler system with the same amount of water applied and by about 78% over the basin system with four times of the amount of water applied. Also, they found that the water efficiency (5.93 kg/mm. donum) was about twice and seven times its value in case of sprinkler and basin, respectively.

Amir and Alchanatis (1992) described the water application pattern (WAP). They said that it is one of the most important factors that determine the instantaneous and the cumulative application rates of moving irrigation machines. This is due to the short application time and the economic incentive to increase the capacity of the machine by increasing both the speed and the discharge. IAR, which can be defined as the discharge per unit of wetted area, is further increased by the use of low pressure heads, which reduce the wetted area of the emitters. An additional factor that might increase the IAR locally, sometimes significantly, is the non-uniformity of the water application pattern (WAP). High IAR, when it exceeds the intake rate of the irrigated soil, may cause water runoff which reduces irrigation efficiency and may cause soil erosion. Probably the most efficient means to avoid excessively high IAR, while maintaining the desired high speed, high discharge and low pressure, is to control both the instantaneous and cumulative WAP (IWAP and CWAP, respectively) of the irrigation machines. This can be accomplished by controlling the factors affecting them, namely, type of emitter, nozzle diameter, jet impact plate, pressure head, spacing between emitters and emitter height.

Wu (1992b) developed the energy gradient line (EGL) approach for drip irrigation lateral line design. He used this approach to calculate directly all emitter flows along the lateral line. He found that the lateral line is designed for an emitter flow variation of 10% or 20%, the actual total discharge applied into the lateral line might be 5% and 10% more or less than the total discharge determined by the operating pressure.

Amir and Dag (1993) studied the effect of type of emitters and amount of water on instantaneous application rates (IAR) under very low pressure (10-15 kpa). IAR is defined as the discharge divided by the wetted area. Their results showed that high IAR increased the uniformity of the wetting pattern and its width, and decreased the depth. On the other hand, high IAR increased water pounding on soil surface and, consequently, water runoff.

Hathoot et al (1994) addressed a new design technique for sprinkler irrigation laterals with equally spaced sprinklers and constant longitudinal slope. They found that, when the head loss constitutes a small percentage of the average pressure head, design pressures at the mainline end of the lateral pipe in both methods (the Darcy-Weisbach friction formula and a Moody diagram) are slightly different. Investigation of the pressure head distribution along the lateral pipe shows that at the middle sprinkler about 86% of the total head loss occurs. Half of the head loss occurs at about 22% of the distance between the first and last sprinklers whereas 75% of the loss occurs at about 38% of the distance mentioned above.

## 3. Materials and Methods

The experiments were conducted in 1993 in the Arid Land Research Center, Tottori University, Japan. The experimental design was split-split plot design method(Gomez; 1984) as follows:

R*A*B*C

where:-

R = replication;

A = type of lateral line;

B = operating pressure head;

C = slope of lateral line.

The statistical analysis was divided into three classes' 3*6*2*5; 3*5*4*5; and 3*3*5*5 because the type of lateral line did not work with all operating pressure heads. The Ultradrip lateral line worked only with 3 and 6 m operating pressure heads. The Ro-drip and Evaflow lateral lines worked with all operating pressure heads except 15 m. RAM, Typhoon, and Twiom lateral lines worked with all operating pressure heads.

The objectives of the present work were to design and evaluate the performance of lateral lines in a drip irrigation system. The experiments were included the following factors:-

### 3.1 Types of lateral line

Six different lateral lines were used in the study as follows:-

#### *3.1.1 RAM*

RAM is the drip line that has been recognized by the American Society of Agricultural Engineers as "a significant new engineering development for agriculture."

a) RAM Laterals

The RAM is integrated into the inside of the drip line by a special 'welding' process. The dripper water inlet is situated at the upper end of the dripper, ( at a height of approximately 6.5 mm from the pipe's wall ), thus-water enters the dripper from an area of free-flowing water-the center of the pipe. This positioning is vitally important, preventing sediments from entering through the water inlet, especially at times when water is not flowing through the system (between operation). The one-piece construction of the RAM permits high reliability factors in deployment and retrieval and prevents the possibility of pipe breakage under high pressure conditions. The shape and small dimensions of the dripper as well as its 'welded' position cause interruption of water flow, resulting in minimum head loss, and permitting the deployment of extremely long driplines.

b) RAM dripper

The RAM dripper is equipped with a unique, independent pressure compensating (P.C.) mechanism. The dripper is constructed with wide water passages, and a free floating diaphragm, designed to vary the volume of water outlet. The diaphragm is activated by the continual differential pressure created by the labyrinth, thus maintaining constant dripper flow over a wide pressure range. The diaphragm is made of a superior grade of synthetic elastomer, (E.P.D.M.), which is chemically inert, and does not react with any known agricultural fertilizer or chemical compound. Figure (3-1) indicates dripline cross section.

**Dripline Cross Section**

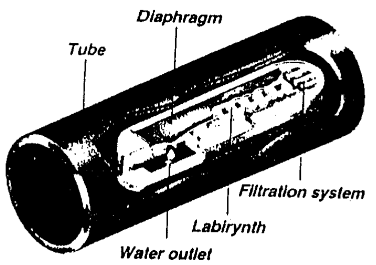


Figure (3-1) indicates dripline cross section of RAM.

c) Advantages of a system utilizing RAM dripline

1- One piece construction, permitting high, varying working pressures without pipe breakage.
2- Long laterals / substantial savings in distribution lines and head controls. Considerable saving in man-hours in deployment and retrieval - 60 - 100 dunam/hour (15 - 25 acres/hour).
3- Uniform dripper discharge dispersal - the dripper's P.C. mechanism assures uniformity in the dripper discharge rate along the entire length of the lateral, even for laterals of over 800 meters in length. This assures uniform growth and ripening for the entire irrigated section, and consequently, higher yields.
4- Resistance against clogging - the RAM dripper is highly reliable and durable, due to its specially designed, sophisticated structure, self cleaning capabilities, and short, wide water passages.
5- RAM enables substantial savings in the number of central regulating units needed, even under extreme topographical conditions and varying

water pressure levels.

6- High reliability - the RAM's special technological advantages and the high quality raw materials from which it is manufactured under stringent quality control, guarantee RAM's outstanding durability and long life. The superior quality of RAM driplines assure an excellent rate of capital return.

7- Wide range of discharges and spacing between drippers - as a result, the RAM may be suited to different soils and crops: field crops, vegetables, flowers, orchards, etc.

### *3.1.2 Typhoon*

a) Typhoon dripperlines

Drippers are welded to the inner- wall of the laterals. The dripperline construction, with its integrated drippers, is highly resistant to mechanical damage.

b) Typhoon drippers

Typhoon drippers feature exclusive technological advantages which guarantee dependability, durability, low sensitivity to clogging and all-round superior performance. A wide water passage effectively prevents clogging, and an inlet consisting of a rack with six openings provides extra filtration and prevents dirt from entering the water passages. The inlet is located 2.8 mm above the tub wall. This special positioning prevents sediment from entering the dripper when the system is not in operation. Figure (3-2) indicates the dripperline cross-section:-

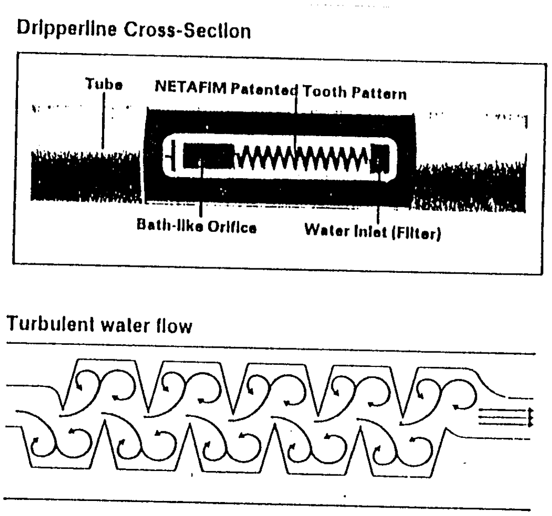


Figure (3-2) indicates the dripperline cross-section of Typhoon

C) Typhoon dripperlines offer a variety of benefits such as :

i- Low initial investment - Typhoon dripperlines are inexpensive and economically viable even for relatively short term use.

ii- Low sensitivity to clogging

* Extra filtration - each dripper has 6 racks for superior filtration. The Typhoon dripper's total filtering area (0.55 m x 7.2 mm) is eight times larger than the water passage area and 20 times larger than many tape orifices.

* The water inlet's position is vitally important in preventing entry of dirt and sediments. The Typhoon dripper's water inlet is located 2.8 mm above the tube wall, so water enters the dripper from the center of the tube-an area of free flowing water.

* Wide water passages - 0.8 mm x 0.8 mm (2.8 l/h dripper).

* Turbulent water low - highly efficient due to Netafim's labyrinth "toothed" water passage.

iii- Uniform performance

* The use of sophisticated computer controlled injection machines in the manufacturing process ensures dripperline accuracy. With a CV value of less than 0.04, the Typhoon's manufacturing variance is the lowest in the irrigation industry.

* Due to the efficient turbulent flow, the variance of flow rate vs. pressure exponent coefficient is less than 0.5; thus, increasing the pressure by 100% will increase flow rate by only 40%.

* Better distribution of fertilizers through dripperlines.

iv- Easy and swift installation - Typhoon dripperlines are quickly and easily installed either on the surface or buried. They can drip up, down and sideways, with virtually no restrictions.

v- Durability - Typhoon dripperlines are not sensitive to deterioration caused by ants and other insects, and can effectively withstand all fertilizers and chemicals in common use such as metil bromaid herbicide.

vi- One-piece construction - The jointless dripperline system minimizes friction loss, enabling longer laterals.

vii- Dripping, not squirting - The Typhoon dripping effect provides optimal uniformity even without burying of dripperlines, resulting in better germination and greater mobility of water in soil.

### *3.1.3 Evaflow*

a) Characteristics:

* Evaflow provides soft watering without scouring, hardening or

splashing the soil.

* With its irrigation pores spaced at short intervals, Evaflow operates consistently with no uneven watering.
* Evaflow permits uniform watering over a long distance (50 to 70 m).
* It can be easily installed and removed.
* It is capable of watering a large area even at low water pressure.
* Evaflow is equipped with a special built-in filter designed to prevent clogging. Figure (3-3) indicates a cross section of Evaflow:-

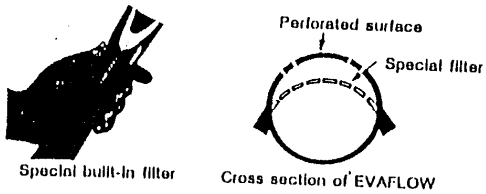


Figure (3-3) indicates a cross section of Evaflow

b) Spray mode:

* For misty spray, install Evaflow with its perforated side (printed surface) facing upward.
* For drip spray, place the perforated side in its downward position.

c) Application:

* A soft mist or drips of water can be sprayed over the entire area of ridges.
* For watering laid-in strawberries, flowering, plants, mushrooms, melons, cucumbers, watermelons, tomatoes, eggplants, and other seedlings.

d) Advantages of a system utilizing Evaflow dripline

* Light in weight and easy to install. No source filters are required
* Capable of simultaneously irrigating a large area at low water pressure.
* Usable for vegetables planted at any intervals.
* Liquid fertilizers can be used.
* Subsurface irrigation is possible.

### *3.1.4 Ro-drip*

a) Characteristics:

* Inner capillary tube partitions from main tube and structures

independently. It has adjust function that fixes the amount of water for all irrigation points.

* A widened water way for prevention of stuffing points, and structures which easily discharges floating matter in irrigation water.
* The connection which is made by the "Youchaku" method creates excellent strength and flexibility of tube.
* Fully turbulent vortex flow action.
* Large flow channel.
* Raised root deflector to resist root intrusion.
* Heat sealed construction with no glue used.
* tough, top quality plastic.

Figure (3-4) indicates the mechanism of the dripper:-

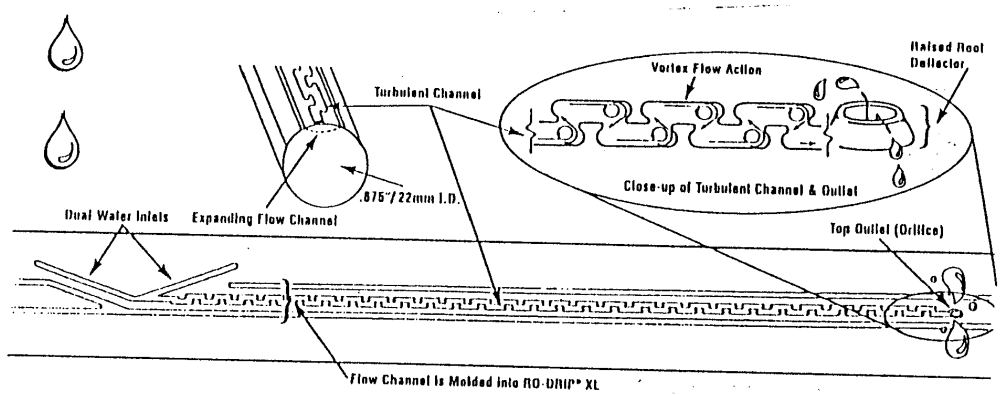


Figure (3-4) indicates the mechanism of the dripper in Ro-drip.

b) Advantages of a system utilizing Ro-drip dripline

* It can be used in the green house without increase the humidity.
* It can be used with surface and subsurface irrigation.
* It can be used to supply a little amount of water and many frequencies irrigation to prevent plant stress.
* Because it is light, changing its position become easy.
* Increased yields.
* Better irrigation efficiency.
* Applied water directly into the root zone.
* Increased conservation of water.
* Reduction of weeds.
* Reduced labor costs.

* Better growth environment for plant.
* Uniform irrigation of long row crops.
* Efficient use of fertilizers and pesticides.

### *3.1.5 Ultradrip*

Characteristics:-

1-In spite of the long distance it is able to irrigate uniformly and there is no ridge-miss.

2-It irrigates a large area (if the ability of the pump is adequate) on low pressure by only one valve and shortens irrigation time.

3-It irrigates automatically easily.

4-Less stuffing of the drip hole; it can be used for a long time.

5-The growth of crop roots is good because the soil is not stuffy and air goes through well.

6-The leaf and stem are not splashed directly; it decreases the stem diseases.

7-It keeps the humidity at a low level in the green house; there is less outbreak out of diseases.

8-The leaking fertilizer is less and irrigates uniformly; liquid fertilizer is absorbed efficiently.

The mechanism of the driptube is indicated in the following Figure (3-5):

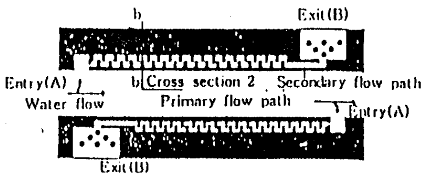


Figure (3-5) : The mechanism of the driptube in Ultradrip.

### *3.1.6 Twiom*

Characteristics:-

1- Quality.
- Virgin resin and rugged construction from Chapin Watermatics, Inc.
- Since 1960 a pioneer in drip irrigation.

2- More choices.
- Outlet spacing.
- Tape thickness.
- Feet per reel at competitive prices.
- Simple design and installation.

3- Higher yields and quality using drip for:
- Row crop fruits and vegetables.
- Vines and trees.
- Nursery/greenhouse potted plants, field flowers, shrubs, trees.

4- More efficient irrigation.
- Water is delivered directly and slowly to the root zone.
- Superior uniformity in wetting pattern.
- Improves leaching of salts away from root zone.
- Patented tortuous (turbulent) flow path resists clogging.

5- Direct-to-the-roots application of:
- Fertilizers.
- Pesticides.
- Soil fumigants.

6- Energy and labor-saving.

7- Suitable for single or multiple cropping.

8- Superior customer service and support.

Figure (3-6) indicates the mechanism of the driptube for the Twiom lateral line:-

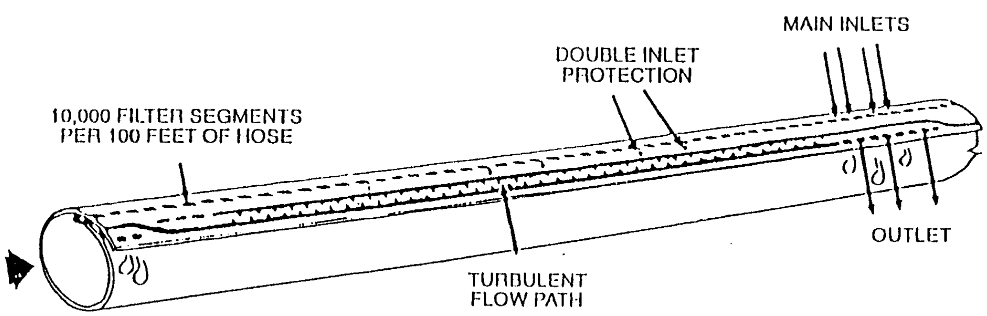


Figure (3-6) indicates the mechanism of the driptube for the Twiom.

### 3.2 Operating head:

The present work included five different pressure heads as follows: 3 , 6 , 9 , 12 , and 15 m at the lateral line inlet. Lateral lines RAM, Typhoon, and Twiom worked with all the previous operating heads, but Ro-drip and Evaflow worked with operating heads 3 , 6 , 9 , and 12 m. Ultradrip could not work with the operating heads more than 6 m. The inlet pressure head was measured by using a pressure gauge which was installed at the lateral line inlet

### 3.3 Slope of lateral line:

Figure (3-1) indicates the different slopes of the lateral line which was used in this research. They were as follows: 2 , 1 , 0 , -1 , -2 %. An engineer's leveler and staff were used to measure the slope of the ground surface. The slope of the lateral line was supported and changed by using wire and bars. Also, wire and bars were used to avoid any deflection in the lateral line during the work.

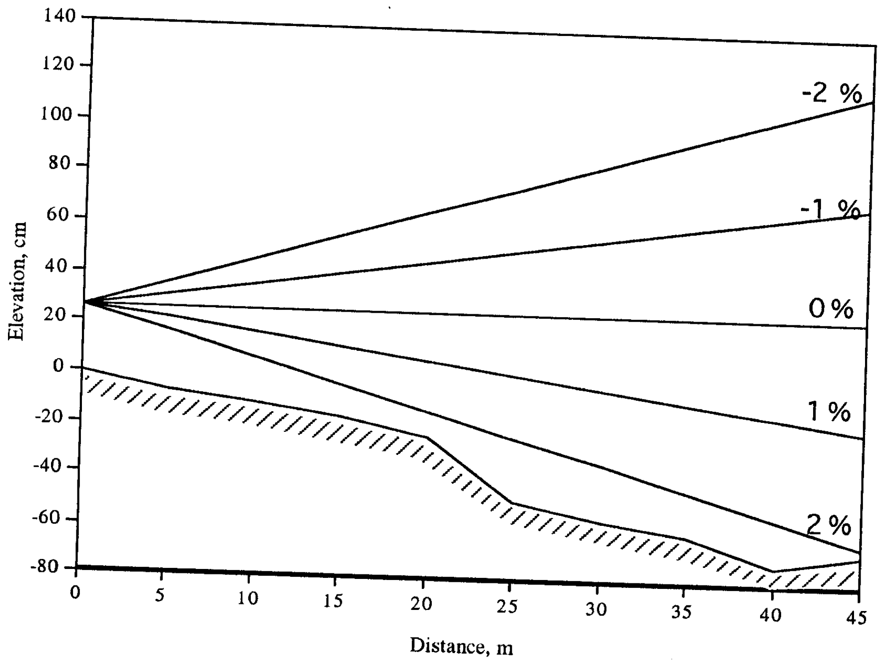


Figure (3-1) : The different slopes of the lateral line

Table (3-1) summarized some characteristics for the previously mentioned lateral lines:-

Table (3-1) some characteristics for lateral lines:-

| Characteristics | Type of lateral lines | | | | | |
|---|---|---|---|---|---|---|
| | RAM | Typhoon | Ro-drip | Ultradrip | Evaflow | Twiom |
| Make | Israel | Israel | U.S.A | Japan | Japan | U.S.A |
| I.D. (mm) | 17.6 | 15.5 | 16.75 | 19 | 21 | 16 |
| Distance between emitters (cm) | 30 | 30 | 20 | 12.5 | 2.5 | 10 |
| Length of lateral line (m) | 45 | 45 | 45 | 45 | 45 | 45 |
| Operating head (m) | 3, 6, 9 12, 15 | 3, 6, 9 12, 15 | 3, 6, 9 12 | 3, 6 | 3, 6, 9 12 | 3, 6, 9 12, 15 |
| Type of lateral | drip emitter | drip emitter | drip tube | drip tube | drip tube | drip tube |

## 3.4 Auxiliary equipment:

The auxiliary equipment utilized in the present work are the following:

1-Electrical valve: it was used to shut off and shut on the lateral line without changing other valves to prevent any oscillation in the lateral line pressure.

2-The flow meter was to measure the water discharge through the lateral line Fig.(3-7).

3-The pressure regulator was used to prevent any oscillation in the pressure during operation Fig.(3-8).

4-The pressure gauge was to measure the operating pressure Fig.(3-8).

5-The mercury manometer was used to measure the head each five meters along the lateral line Fig.(3-8).

6-The calibrated cylinder was for collecting emitter discharge every five meters along the lateral line Fig.(3-9).

7-The engineer's leveler and telescopic staff were used to measure the slope of the ground and also for land leveling the ground in the green house . The dimension of green house were 8m x 47m. There were two big ventilators installed above every door of the green house.

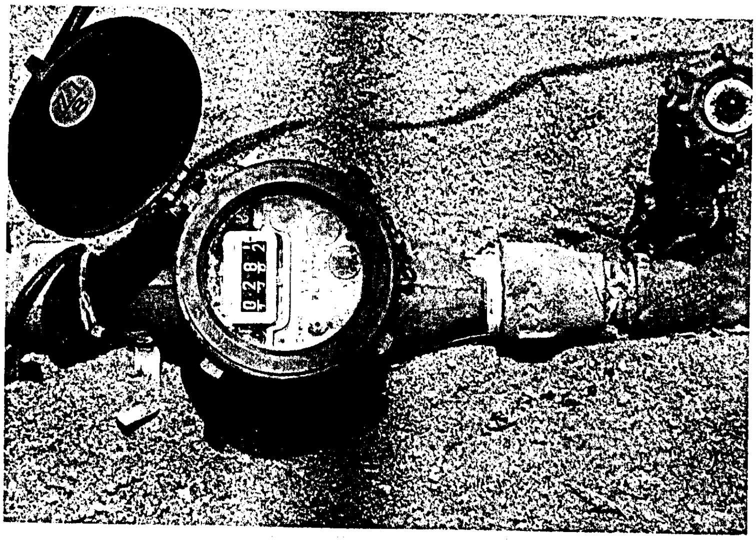

Fig. (3-7): The flowmeter

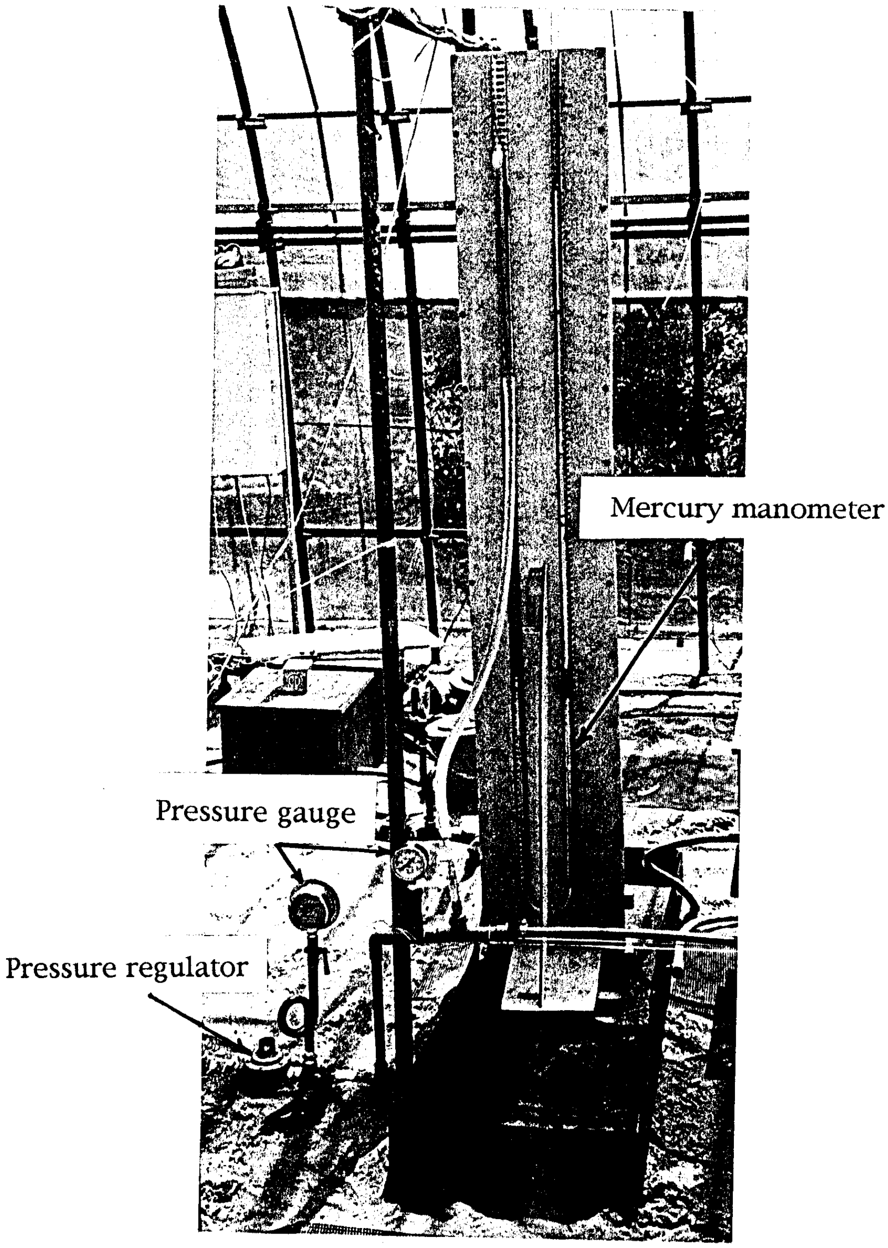


Fig.(3-8): Pressure regulator, pressure gauge and mercury manometer.

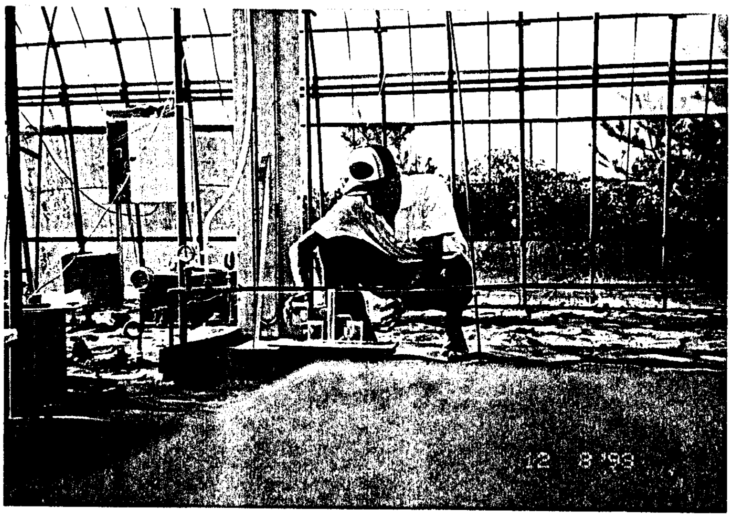


Fig.(3-9) : The calibrated cylinder.

## 3.5 *The dependent factors which were studied and indicated as follows:-*

**1. Emitter flow rate-Pressure head relationship:**

Discharge-pressure relationship was calculated from the following equation (Warrick and Yitayew, 1988):-

$$q = kh^c \text{ ..........................................(3-1)}$$

where:-

k, c = Equation constants

$q$ = Emitter flow rate $(cm^3/\min)$

$h$ = Pressure head at emitter (m)

**2. Manufacturer's coefficient of variation ($CV$):**

Manufacturer's coefficient of variation ( $CV$ ) was calculated from the following equation (ASAE, 1991):-

$$CV = \frac{s}{q'} x100 \text{ ....................................(3-2)}$$

where:-

$s$ = Standard deviation of emitters flow rate

$q'$ = Emitter flow rate average $(cm^3/\min)$

**3. Distribution of emitters discharge along the lateral lines($q_i$):**

Emitter discharge ($q_i$) was measured by collecting emitters discharge in a calibrated cylinder during a limited time at 5 meter' intervals along the lateral lines.

**4. Head distribution along the lateral line ($h_i$):**

Head distribution ($h_i$) at 5 m intervals was measured by using a mercury manometer.

**5-Emitter flow rate variation ($q_{var}$):**

Emitter flow rate variation ($q_{var}$) was calculated from the following equation (Wu, 1992a):-

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \text{ .......................................(3-3)}$$

where:-

$q_{max}$ = Maximum emitters flow rate $(cm^3/\min)$

$q_{min}$ = Minimum emitters flow rate $(cm^3/\min)$

6. Head variation ($h_{var}$):

The head variation ($h_{var}$) along the lateral line was calculated from the following equation (Wu, 1992a) :-

$$h_{var} = \frac{h_{max} - h_{min}}{h_{max}} \quad \text{.................................(3-4)}$$

where:-

$h_{max}$ = Maximum head (m)

$h_{min}$ =Minimum head (m)

7. Distribution of uniformity ($DU$):

The distribution of uniformity is a useful indicator of distribution problems. A low $DU$ indicates that excessive deep percolation losses will occur if adequate irrigation is supplied to all areas. The following equation is used to calculate $DU$ (Anon, 1978):

$$DU = \frac{q'_l}{q'} x100 \quad \text{.................................(3-5)}$$

where:-

$q'_l$ = Average low quarter depth of water in filtrated $(cm^3/\text{min})$

8. Head loss ($\Delta H$):

Head loss is the difference between head value at inlet and outlet of lateral lines.

9. Coefficient of uniformity ($UC$) :

Coefficient of uniformity was calculated from the following equation (Christiansen, 1942):-

$$UC = \left(1 - \frac{\sum |q - q'|}{nq'}\right) x100 \quad \text{..............................(3-6)}$$

where:-

$n$ = Number of observed emitters

# 4. *Results and discussion*

The results will be indicate the effect of independent factors on the following:

## 4.1 Emitter flow rate-Pressure head relationship:

For hydraulic design, the variation of emitter flow is determined based on the pressure variation in the drip system according to the relationship shown in the following equation.

$$q=kh^c$$

where:-

$k, c$ = Equation constants

$q$ = Emitter flow rate ($cm^3/\text{min}$)

$h$ = Pressure head (m)

The relationship between emitter flow rate and pressure head shown in Fig. 4-1. A curve in each figure shows the fitting of the equation to experiment result and $k$ and $c$ values were obtained as follows:

| Lateral line | $k$ | $c$ | $R^2$ |
|---|---|---|---|
| RAM | 37.734 | 0.039 | 0.364 |
| Typhoon | 11.832 | 0.442 | 0.980 |
| Ro-drip | 04.850 | 0.819 | 0.967 |
| Ultradrip | 00.346 | 2.768 | 0.984 |
| Evaflow | 04.566 | 1.335 | 0.964 |
| Twiom | 08.392 | 0.487 | 0.996 |

The literatures (Solomon and Keller; 1978, Harry Soom; 1981, Warric and Yitayew; 1988, Yitayew and Warric; 1988, Wu; 1992a and Hathood et al; 1993) indicated the value of $c$ constant among 0 to 1. This value depends on type of emitter and flow conditions. Its value equals zero with a pressure compensated emitter, 1.0 with laminar flow, and 0.5 with full turbulent flow.

The result agreed with those in the literatures in case of the RAM, Typhoon, Ro-drip, and Twiom but differed with the Ultradrip and Evaflow. The differences with Ultradrip and Evaflow were due to the type of these lateral lines. The material of the lateral lines with emitters is plastic that enlarges with high heads. The results showed that manufacturing tolerances could cause relatively large fluctuation in diameter (plastic tube) when the high pressure head was used, especially with the Evaflow and Ultradrip lateral line.

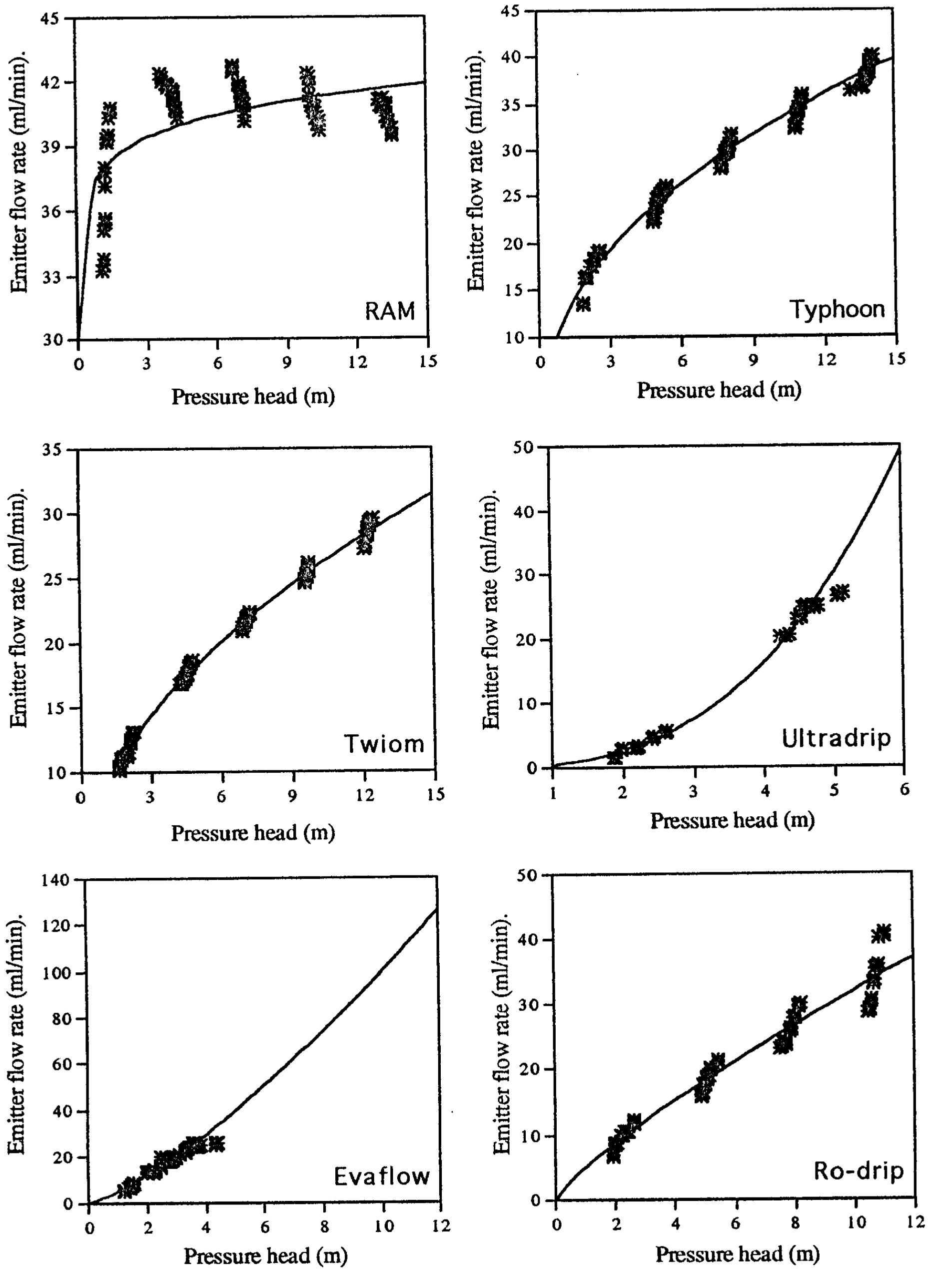


Fig. 4-1: Emitter flow rate-pressure head relationship with different type of lateral lines.

## 4.2 Manufacturer's coefficient of variation ($CV$)

For any drip irrigation emitter or orifice in the lateral line, there will be manufacturer's variation that depends on the manufacturer's quality control in production. It is important to consider the manufacturer's variation in the selection of emitters or laterals and in the lateral line design. Samples of emitters (18 emitters from each type of lateral line) were selected randomly and tested under fixed operating pressure head. The manufacturer's variation is actually caused by the nonuniform production from the manufacturer.

Table 4-1 and Fig. 4-2 show the effect of type of lateral line and operating pressure head on the manufacturer's coefficient of variation (Eq. 3-2).

Table 4-1: Effect of type of lateral line and operating pressure head on manufacturer's coefficient of variation.

| Operating | Manufacturer's variation, % | | | | | |
|---|---|---|---|---|---|---|
| head, m | RAM | Typhoon | Ro-drip | Ultradrip | Evaflow | Twiom |
| 3 | 3.08 | 1.93 | 12.62 | 20.05 | 43.12 | 3.44 |
| 6 | 3.17 | 1.30 | 10.77 | 10.64 | 50.10 | 2.84 |
| 9 | 3.28 | 1.27 | 16.23 | - | 38.99 | 3.17 |
| 12 | 2.00 | 1.70 | 8.92 | - | 52.44 | 3.17 |
| 15 | 3.60 | 2.02 | - | - | - | 4.07 |

The experiments indicated that the manufacturer's coefficient of variation was affected by operating head and type of lateral line. Typhoon lateral line was the best type with $CV$ values of 1.93, 1.30, 1.27, 1.70, and 2.02 % for operating heads 3, 6, 9, 12, and 15 m respectively. Evaflow was the worst type with $CV$ values of 43.12, 50.10, 38.99, and 52.44 % for operating heads 3, 6, 9, and 12 m respectively.

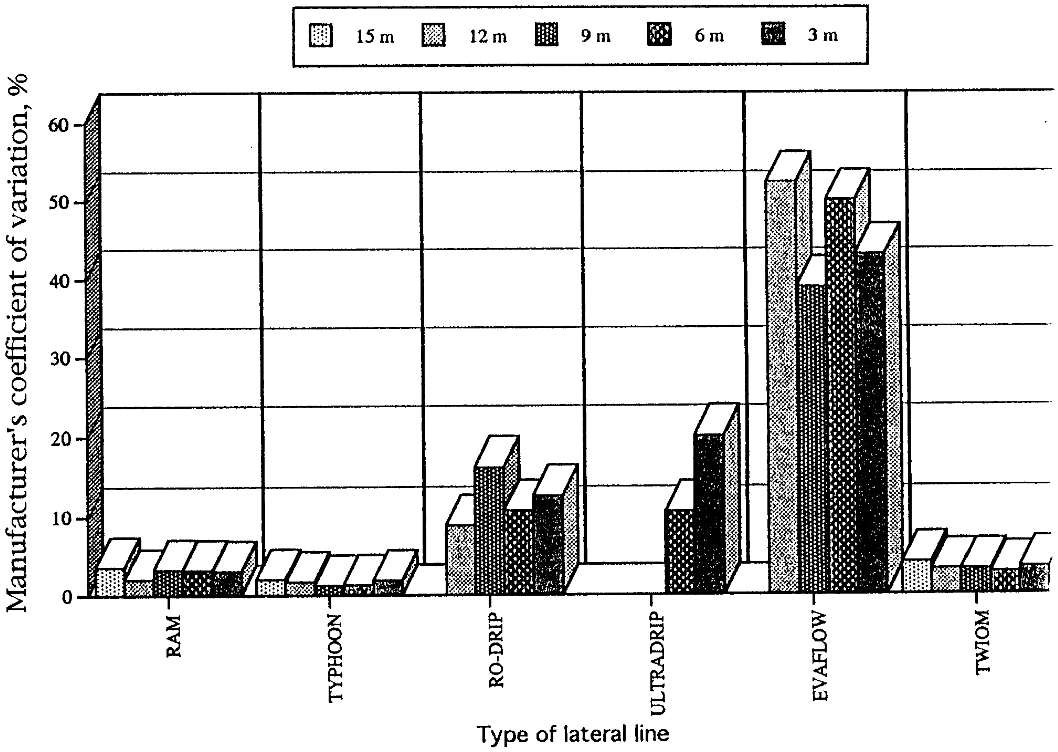


Fig. (4-2): Manufacturer's coefficient of variation for differenet type of lateral lines at different inlet pressure head.

### 4.3 Distribution of emitters discharge along the lateral lines($q_i$)

Figures (4-3 to 4-8) and Figures ( 5-1 to 5-5 in Appendix) indicate the distribution of emitter flow rates along lateral line at the different type and slope of lateral line and operating pressure head.

Emitter flow rate along the lateral line was affected by inlet pressure head and slope of lateral line. Generally, it increased by increasing both operating pressure head and slope of lateral line except RAM lateral line. Emitter flow rate in RAM decreased slightly by increasing operating pressure head over 6m, but decreased by using 3 m inlet pressure head because this line provides by compensating emitters. The Evaflow lateral line is to be perforated tube. The emitter flow rate at the beginning was much higher than that at the end of the Evaflow lateral line especially at high operating pressure head due to enlargement of diameter of the lateral line. The best distribution of emitter flow rate along the lateral line was in the Typhoon and Twiom lateral lines.

Figures (5-6 to 5-11 n Appendix) show the frequency of relative emitter flow rate for different types of lateral lines under different conditions of operating pressure heads and slope of lateral line. These curves indicate the distribution of emitter flow rate around the average emitter flow rate. The best lateral line is the one which gives high frequency when the relative emitter flow rate equals one. The relative emitter flow frequency in the RAM lateral line was similar when using operating pressure head greater than 6 m but differed at 3 m pressure head because this type is a pressure compensating emitter. The Evaflow lateral line gave the lowest values of frequency for relative emitter flow rate because the manufacturer's coefficient of variation for this line is too big. The other lateral lines followed the same trend.

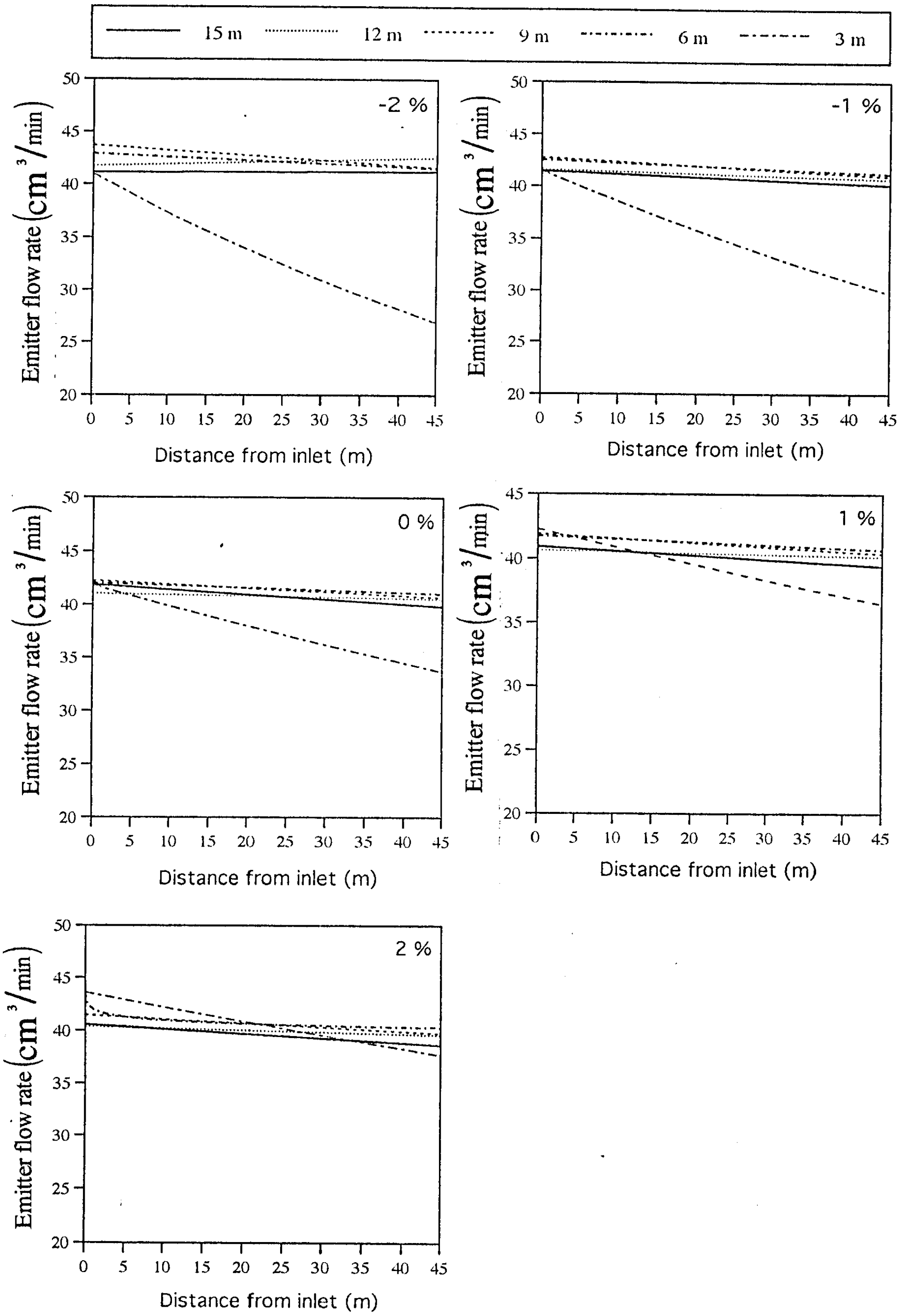


Fig. (4-3): Effect of operating pressure head and slope of lateral line on emitter flow rate in RAM.

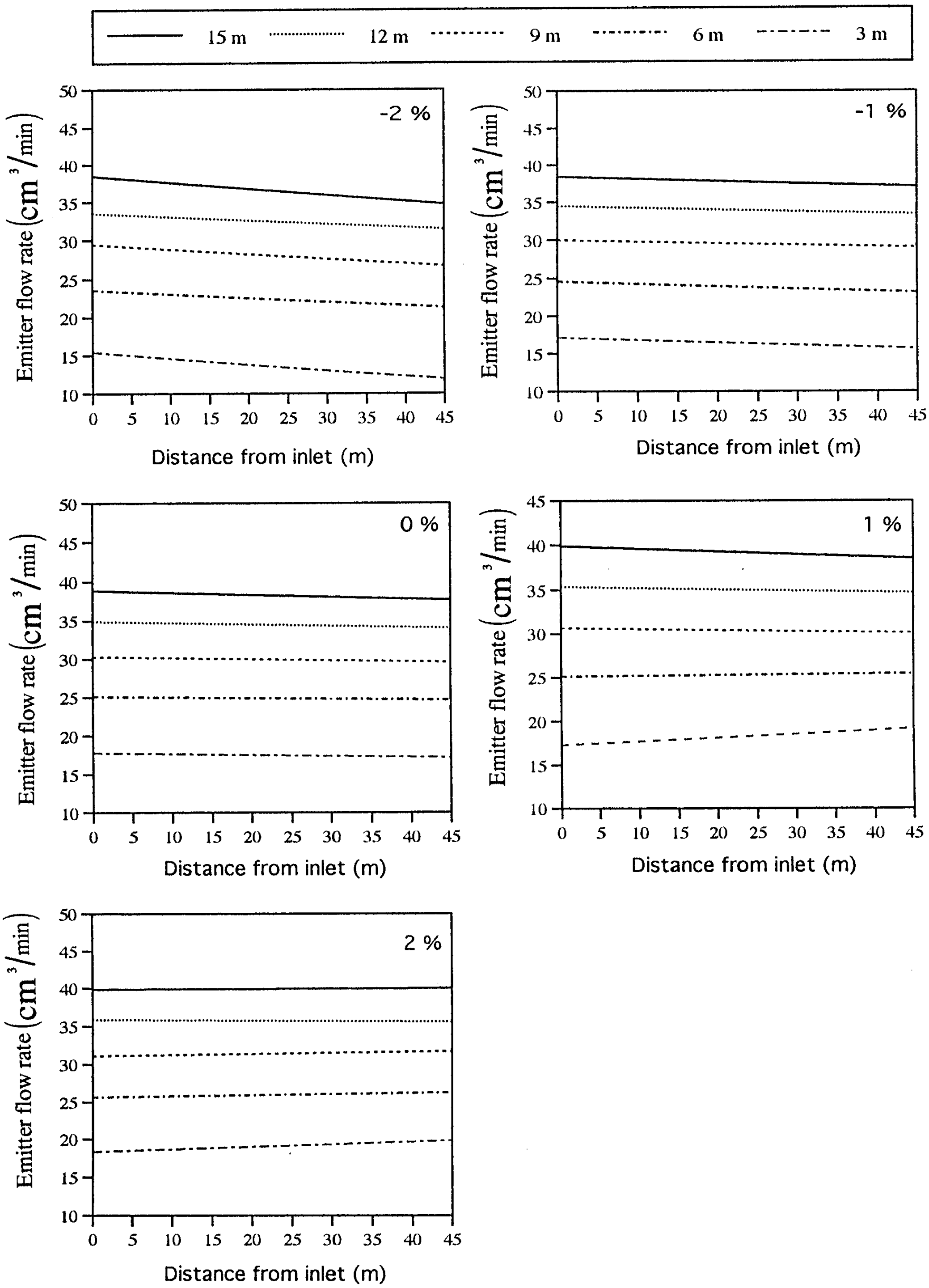


Fig. (4-4): Effect of operating pressure head and slope of lateral line on emitter flow rate inTyphoon.

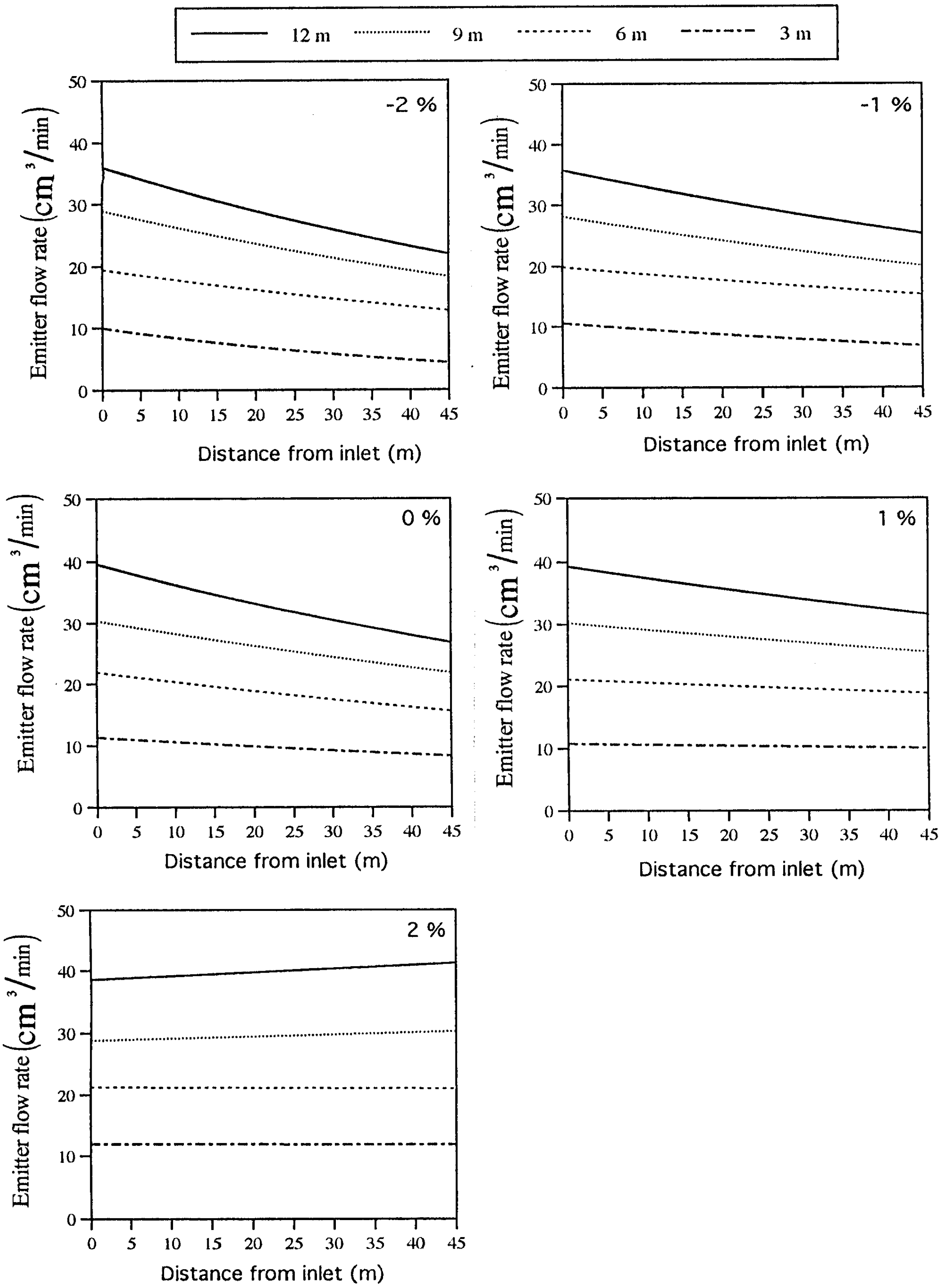


Fig. (4-5): Effect of inlet pressure head and slope of lateral line on emitter flow rate in Ro-drip.

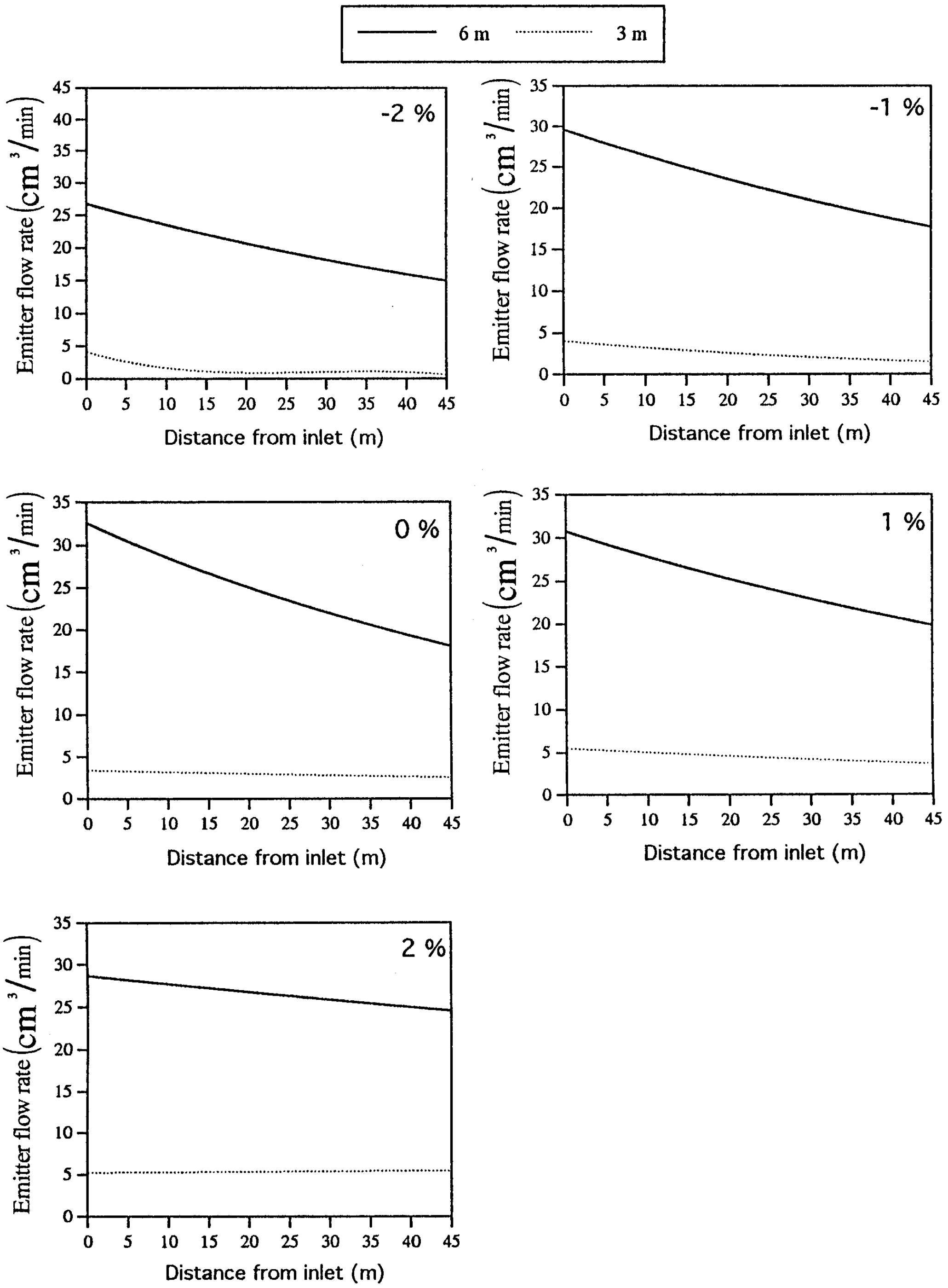


Fig. (4-6): Effect of inlet pressure head and slope of lateral line on emitter flow rate in Ultradrip.

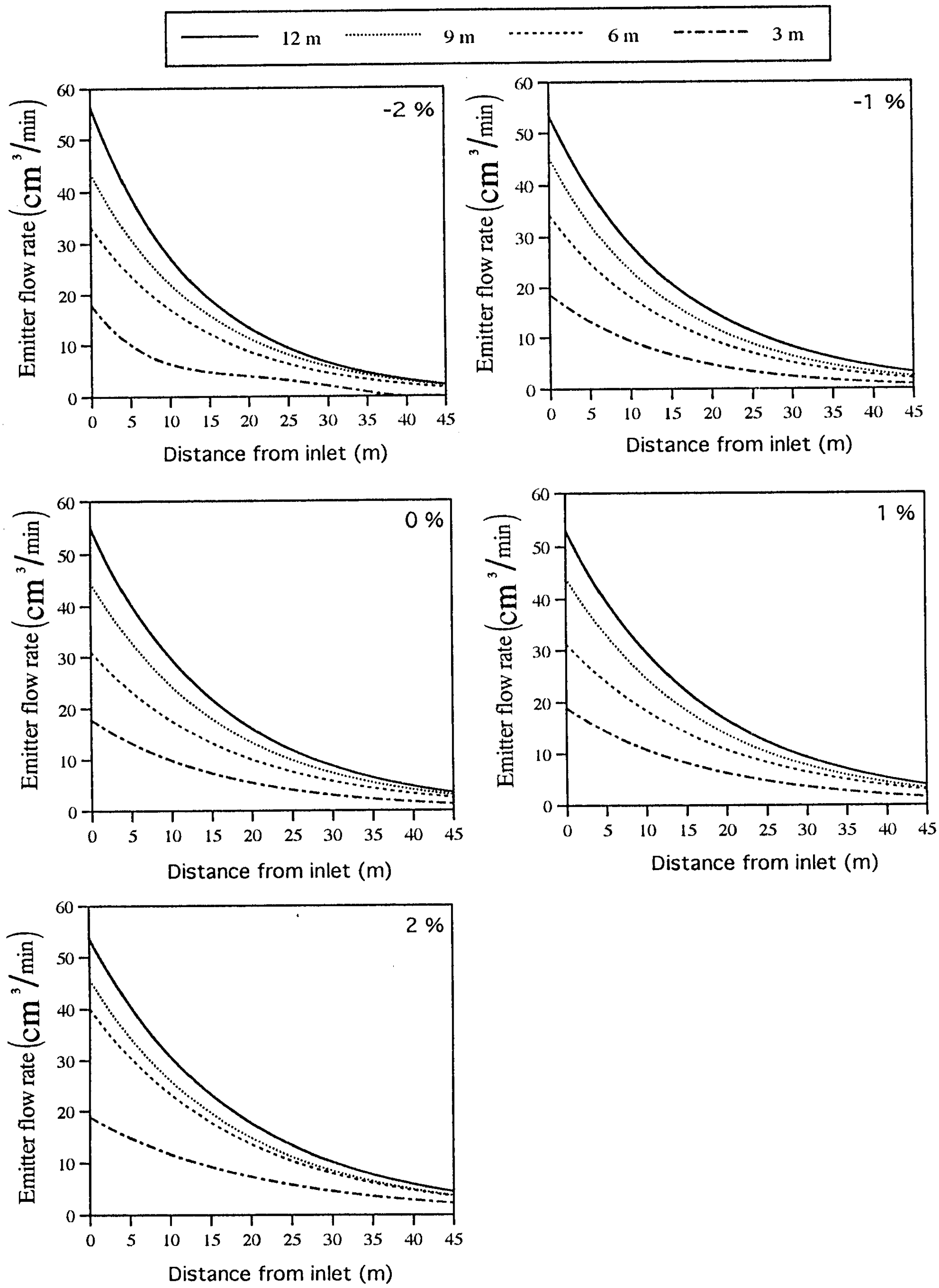


Fig. (4-7): Effect of inlet pressure head and slope of lateral line on emitter flow rate in Evaflow.

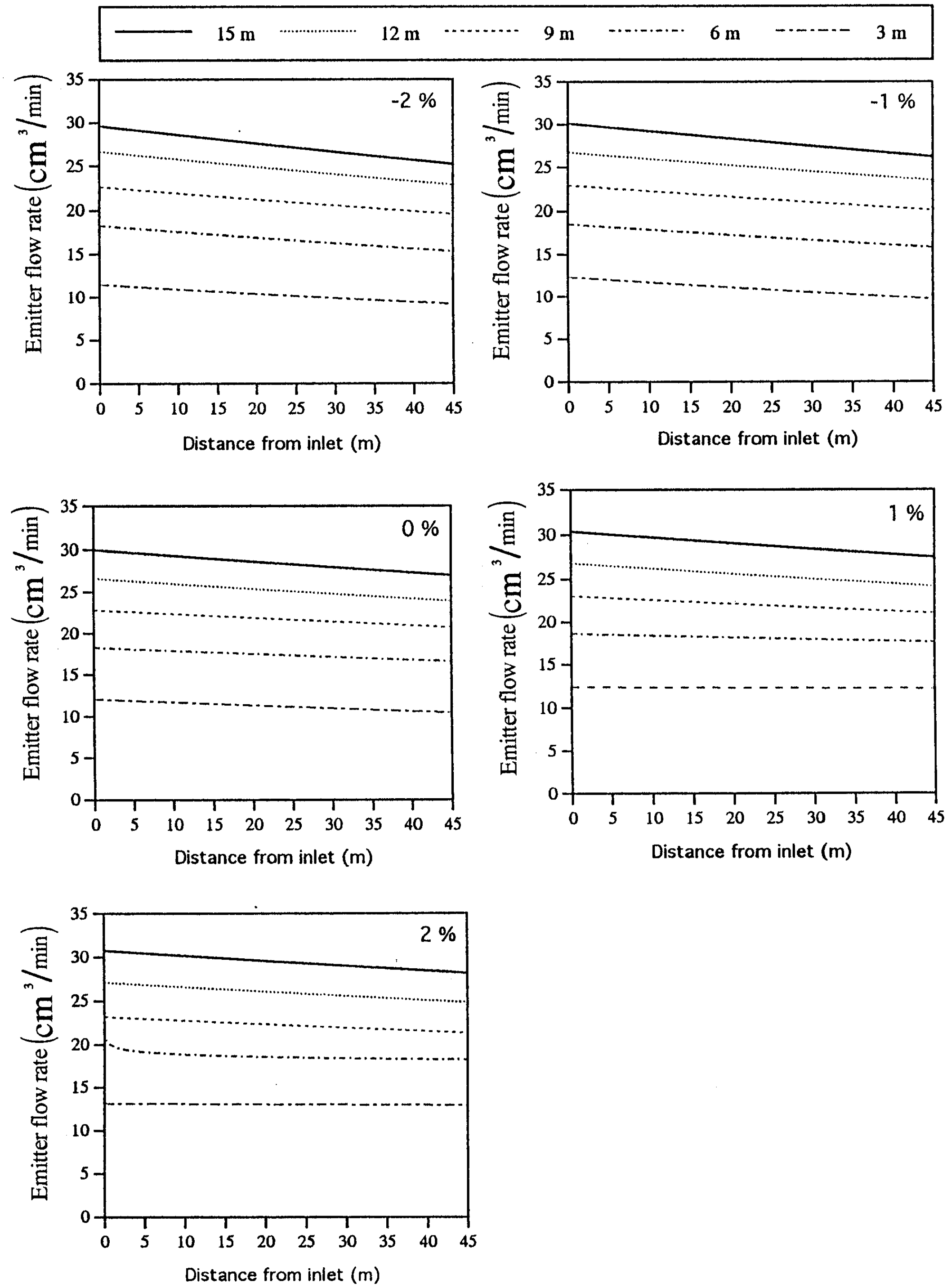


Fig. (4-8): Effect of inlet pressure head and slope of lateral line on emitter flow rate in Twiom.

## 4.4 Head distribution along the lateral line ($h_i$)

Figures (4-9 to 4-14) show the change of the pressure head along the distance from the inlet for the different types of lateral lines under the conditions of different operating pressure heads and slopes of lateral line. The results indicated that the pressure distribution along the lateral line followed the same trend with all types of lateral line. The pressure head decreased with the distance from the lateral inlet

Figures (5-12 to 16 in Appendix) show the pressure head distribution is similar in all types of lateral lines except the Evaflow lateral line. The pressure head in the Evaflow was decreased because its discharge decreased significantly during the first 5 meters, especially with the operating pressure heads 12, 9, 6 m respectively. When the 3 m operating head was used, the head distribution followed the same trend as the other lateral line. The Typhoon lateral line gave the best result for pressure head distribution.

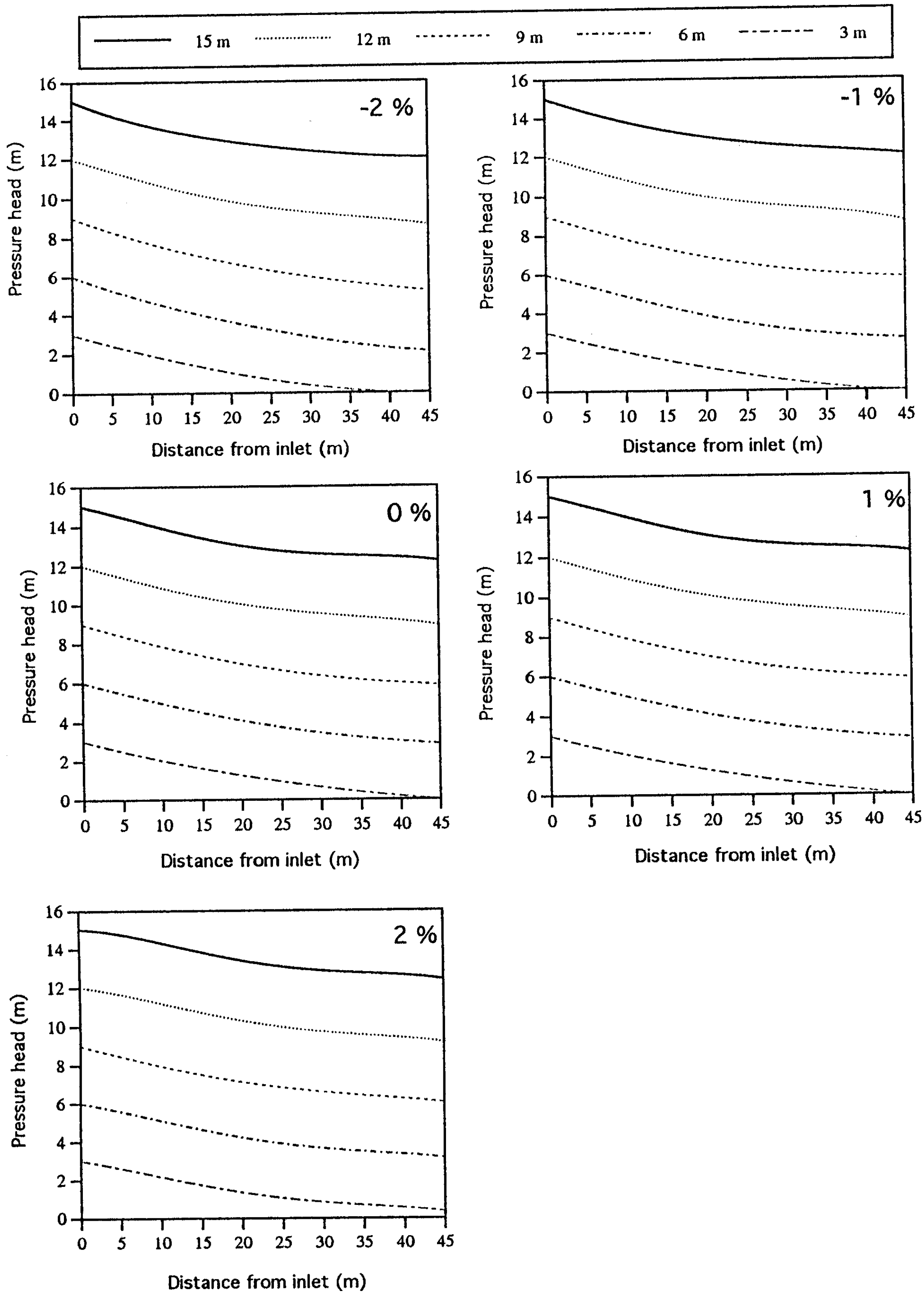


Fig. (4-9): Effect of inlet pressure head and slope of lateral line on pressure head distribution in RAM.

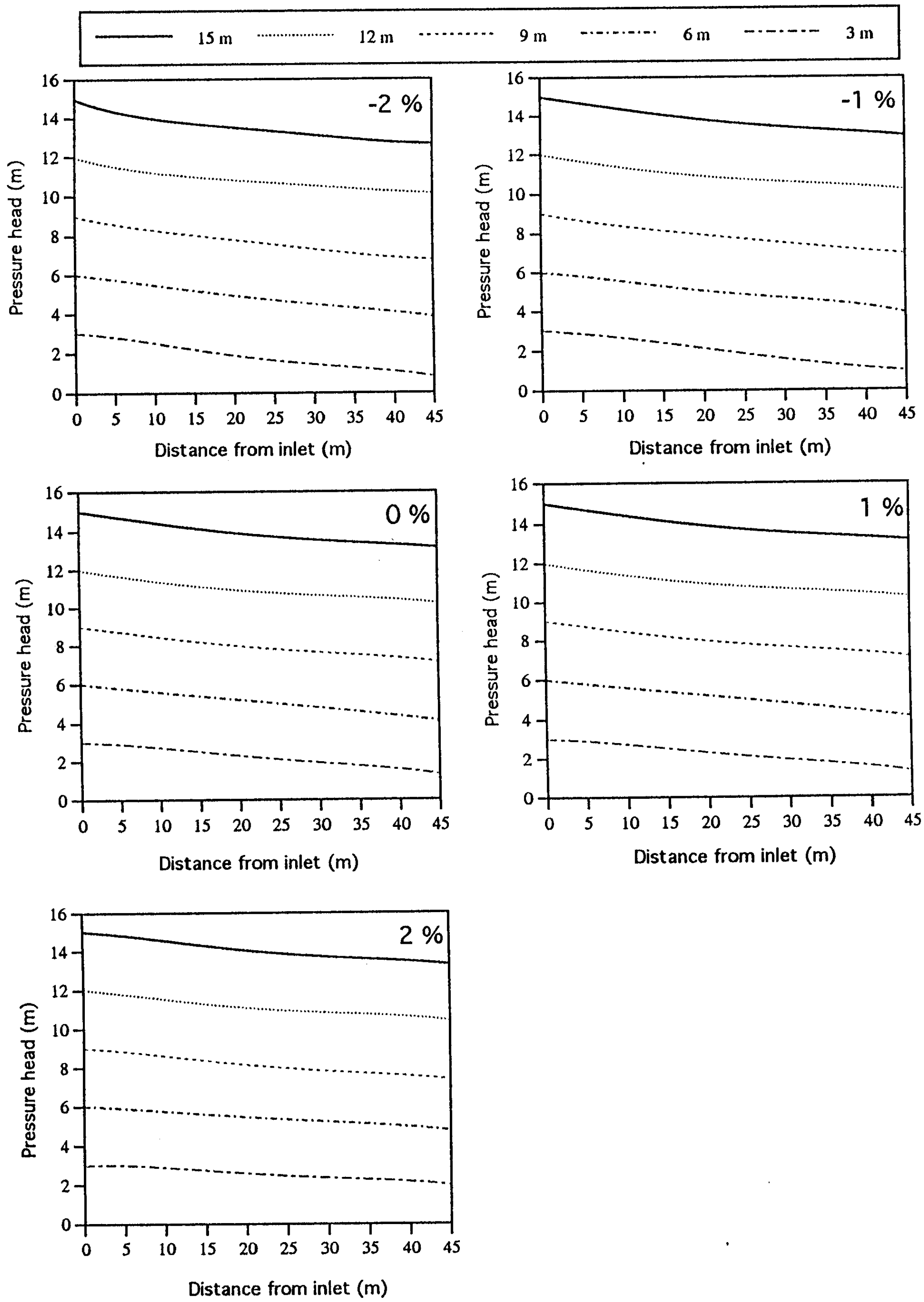


Fig. (4-10): Effect of inlet pressure head and slope of lateral line on pressure head distribution in Typoon.

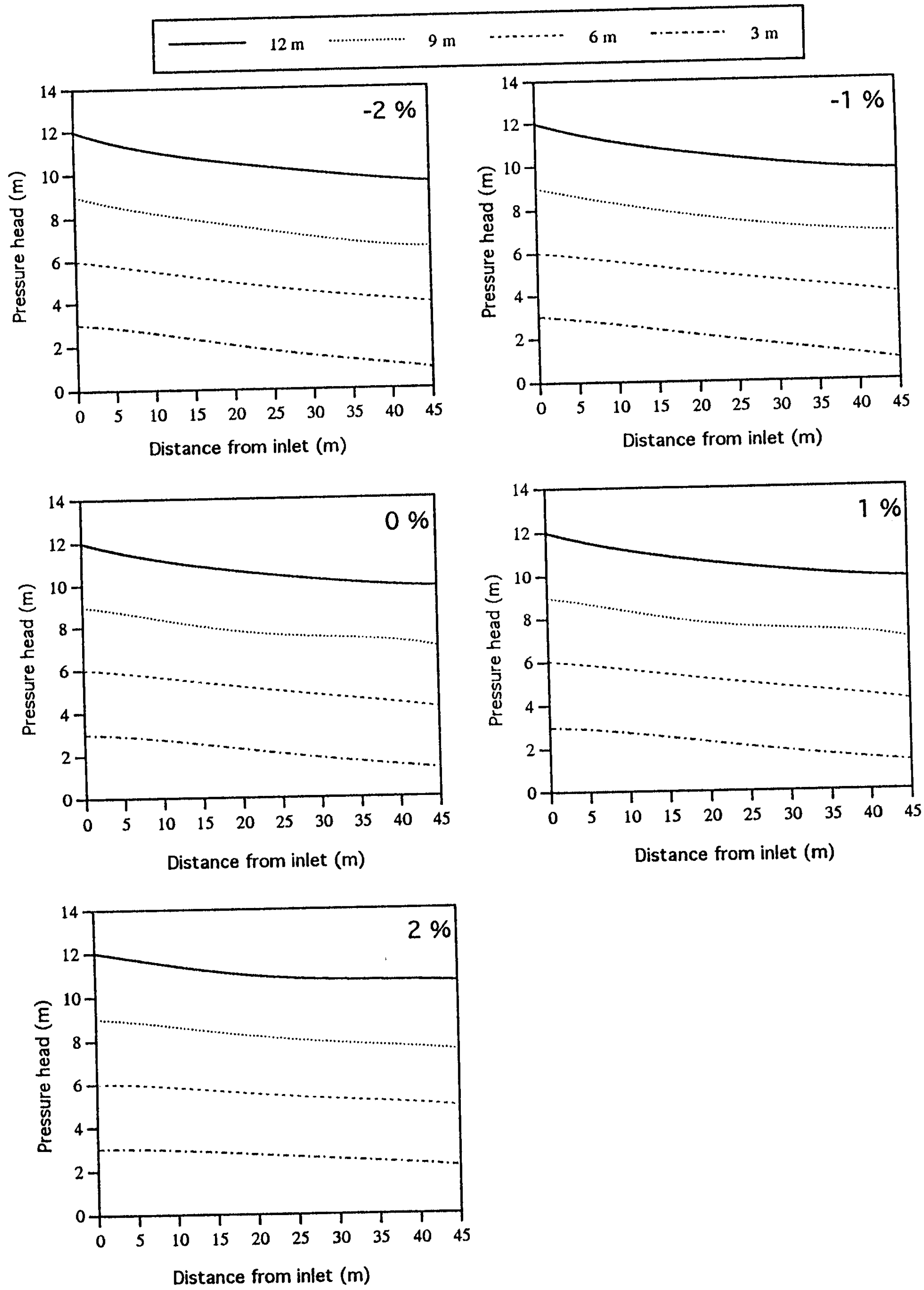


Fig. (4-11): Effect of inlet pressure head and slope of lateral line on pressure head distribution in Ro-drip.

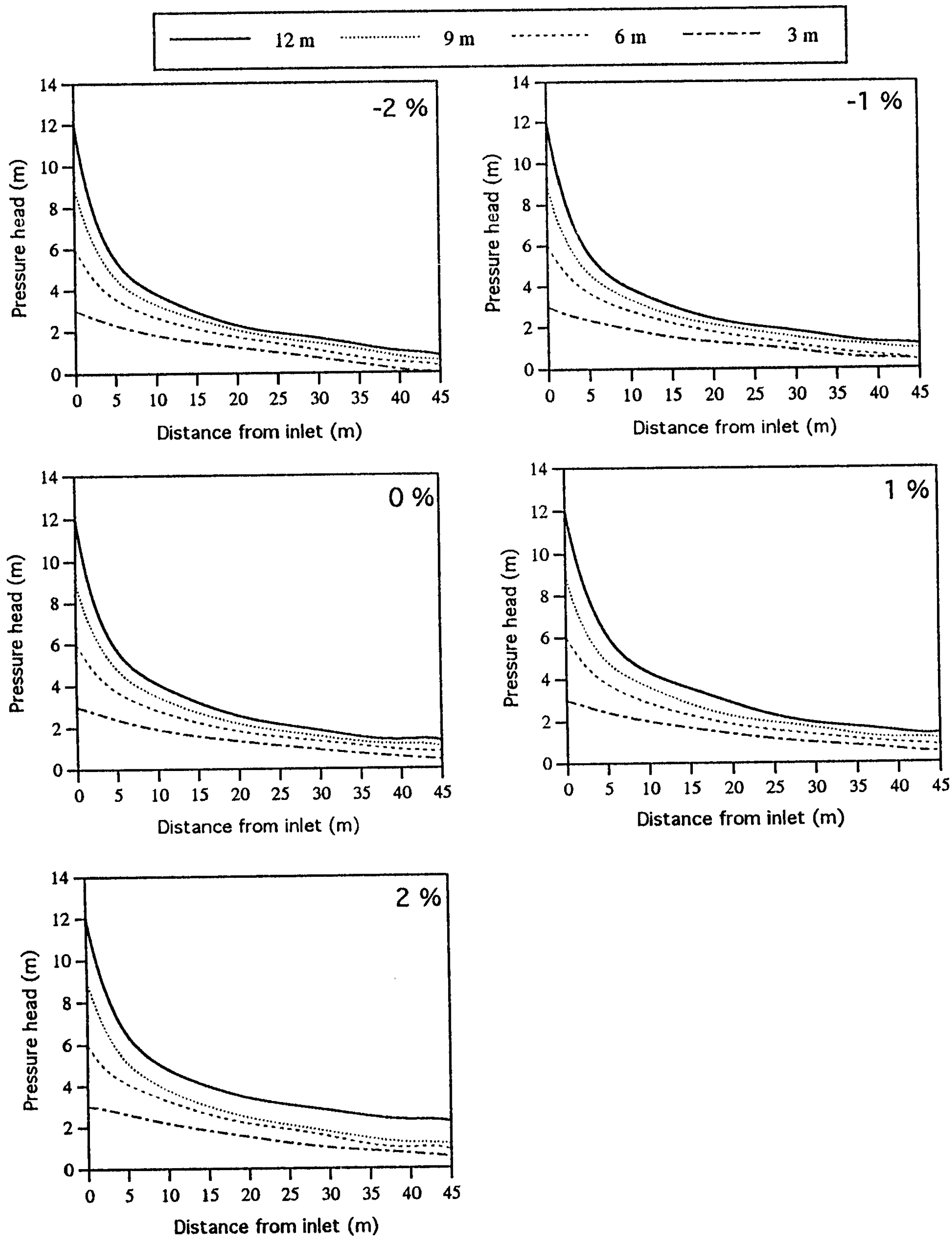


Fig. (4-12): Effect of inlet pressure head and slope of lateral line on pressure head distribution in Evaflow.

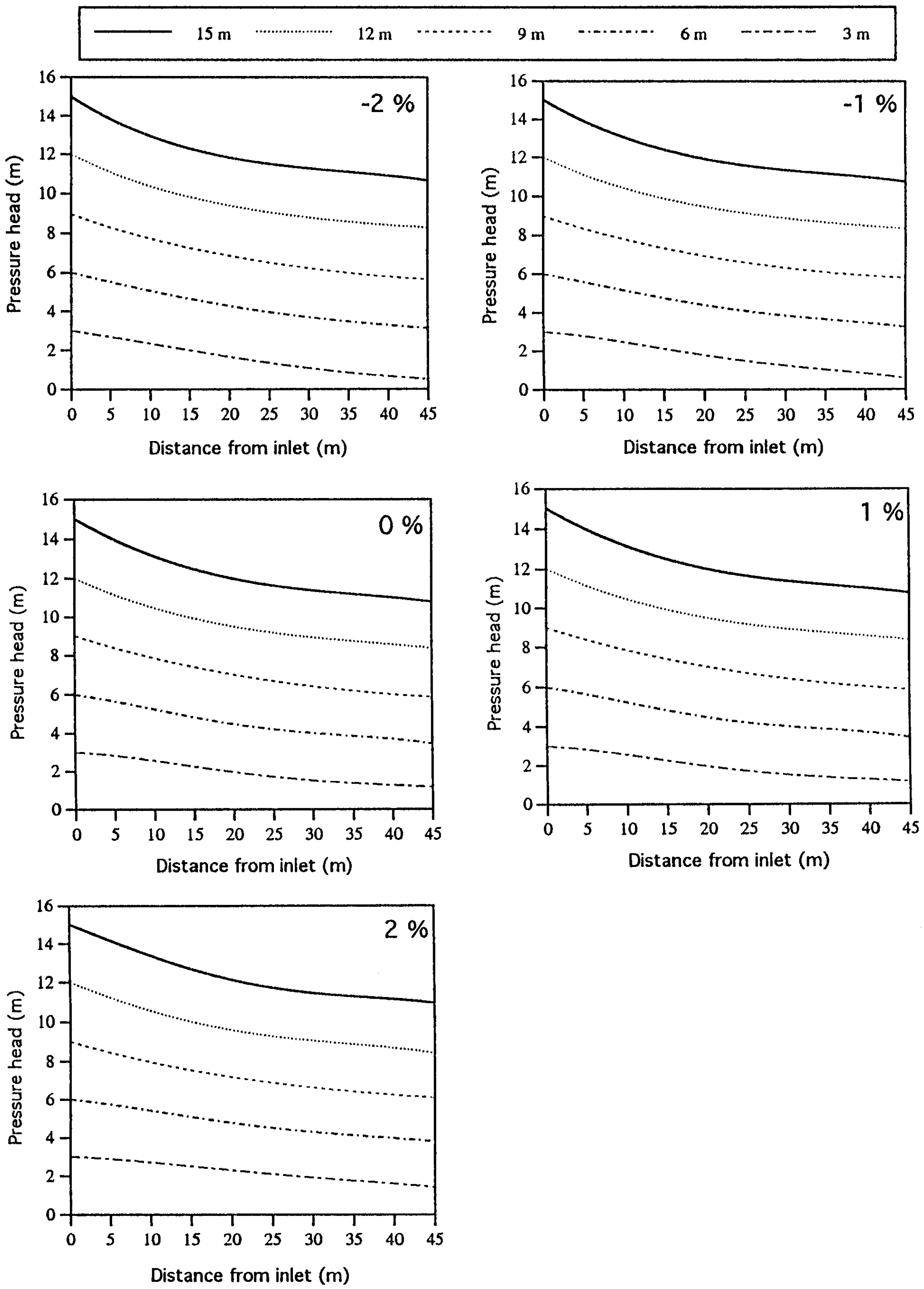


Fig. (4-13): Effect of inlet pressure head and slope of lateral line on pressure head distribution in Twiom.

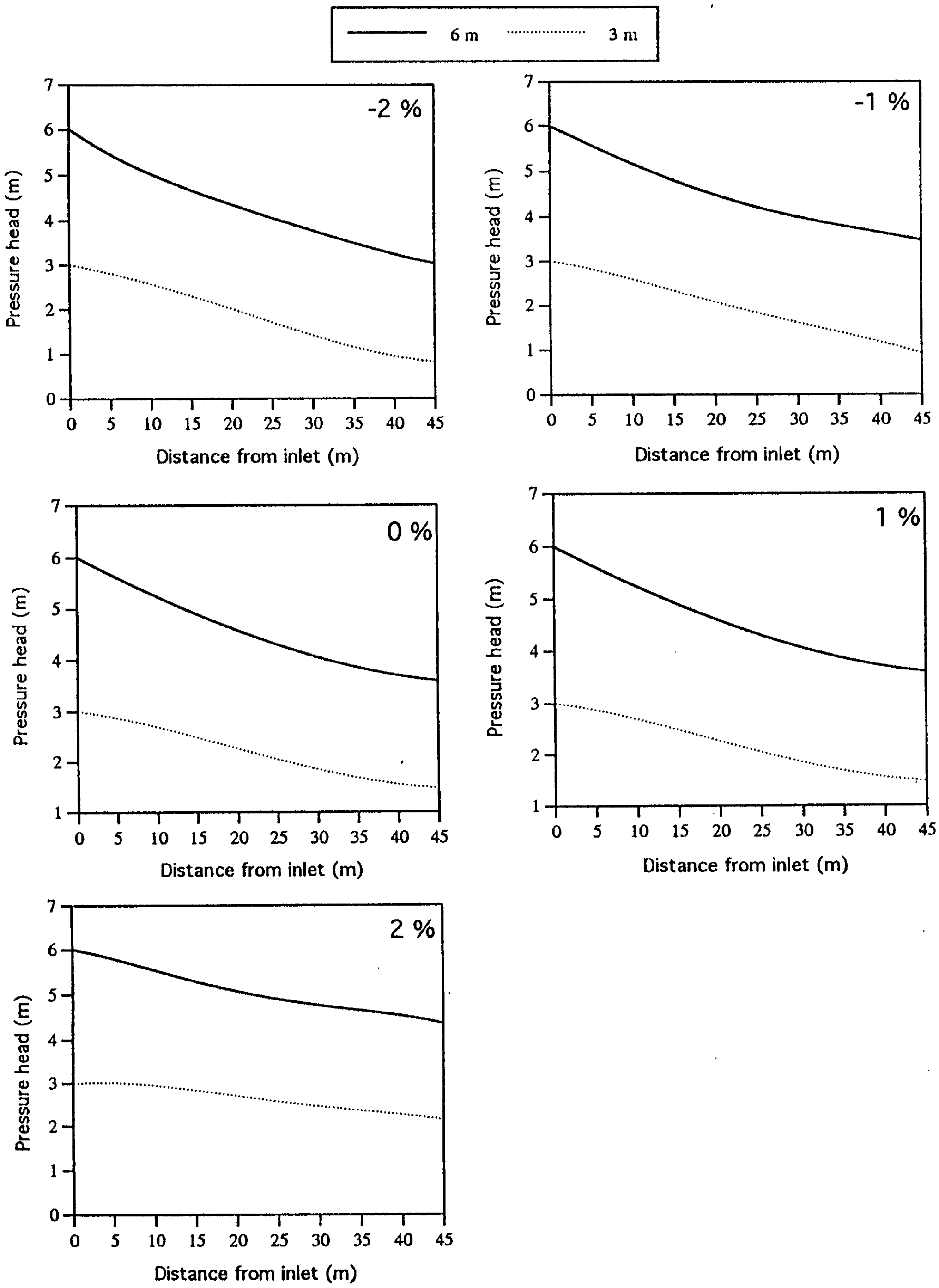


Fig. (4-14): Effect of inlet pressure head and slope of lateral line on pressure head distribution in Ultradrip.

## 4.5 Emitter flow rate variation ($q_{var}$)

Emitter flow variation is a newly added criterion for the hydraulic design of drip irrigation systems instead of the traditional statistical variation. It can be determined by only the maximum and minimum emitter flow rates for a drip irrigation system design. A significant advantage is that the location of $q_{max}$ and $q_{min}$ can be easily found along a lateral line and the $q_{var}$ can be easily determined when the emitter flow variation is used in the hydraulic design . The effect of type and slope of lateral line and inlet pressure head and their interaction is indicated in Figures (4-15 and 4-16) and Tables (4-2 to 4-6).

The statistical analysis of emitter flow rate variation indicated a high significant effect by operating head, type and slope of lateral lines (Table 5-1 in Appendix). The values of these variations were: 14.37, 14.73, 41.64, 56.05, 95.03, and 14.36 % for the RAM, Typhoon, Ro-drip, Ultradrip, Evaflow, and Twiom respectively(Table 4-2). They were: 18.88, 10.09, 10.31, 9.67, and 10.23 % for operating heads of 3, 6, 9, 12, and 15 m respectively(Table 4-2). The emitters flow rate variations were: 28.95, 27.57, 28.23, 27.66, and 30.60 % for lateral line's slope -2, -1, 0, 1, and 2 % respectively (these values were calculated based on the average of the values in Table (4-2). The results indicated that the best operating conditions that give the lowest emitter flow rate variations were with the Typhoon lateral line at 15 m head and 2 % slope (as shown in Table 4-6). The worst lateral lines with these variations were the Evaflow and Ultradrip at 3 m head and -2% slope (see Table 4-6).

Regression analysis was conducted to determine the relationship between emitter flow variation and pressure head variation in this study. The following regression equations for different lateral lines which were calculated from the data in Table (5-2) in the appendix are.

| | | |
|---|---|---|
| $q_{var} = 0.061 - 0.080\log(1 - h_{var})$ | R=0.924 | RAM |
| $q_{var} = 0.072 - 0.298\log(1 - h_{var})$ | R=0.712 | Typhoon |
| $q_{var} = 0.025 - 0.198\log(1 - h_{var})$ | R=0.695 | Twiom |
| $q_{var} = 0.330 - 0.465\log(1 - h_{var})$ | R=0.615 | Ro-drip |
| $q_{var} = 0.893 - 0.057\log(1 - h_{var})$ | R=0.782 | Evaflow |
| $q_{var} = 0.235 - 1.139\log(1 - h_{var})$ | R=0.867 | Ultradrip |

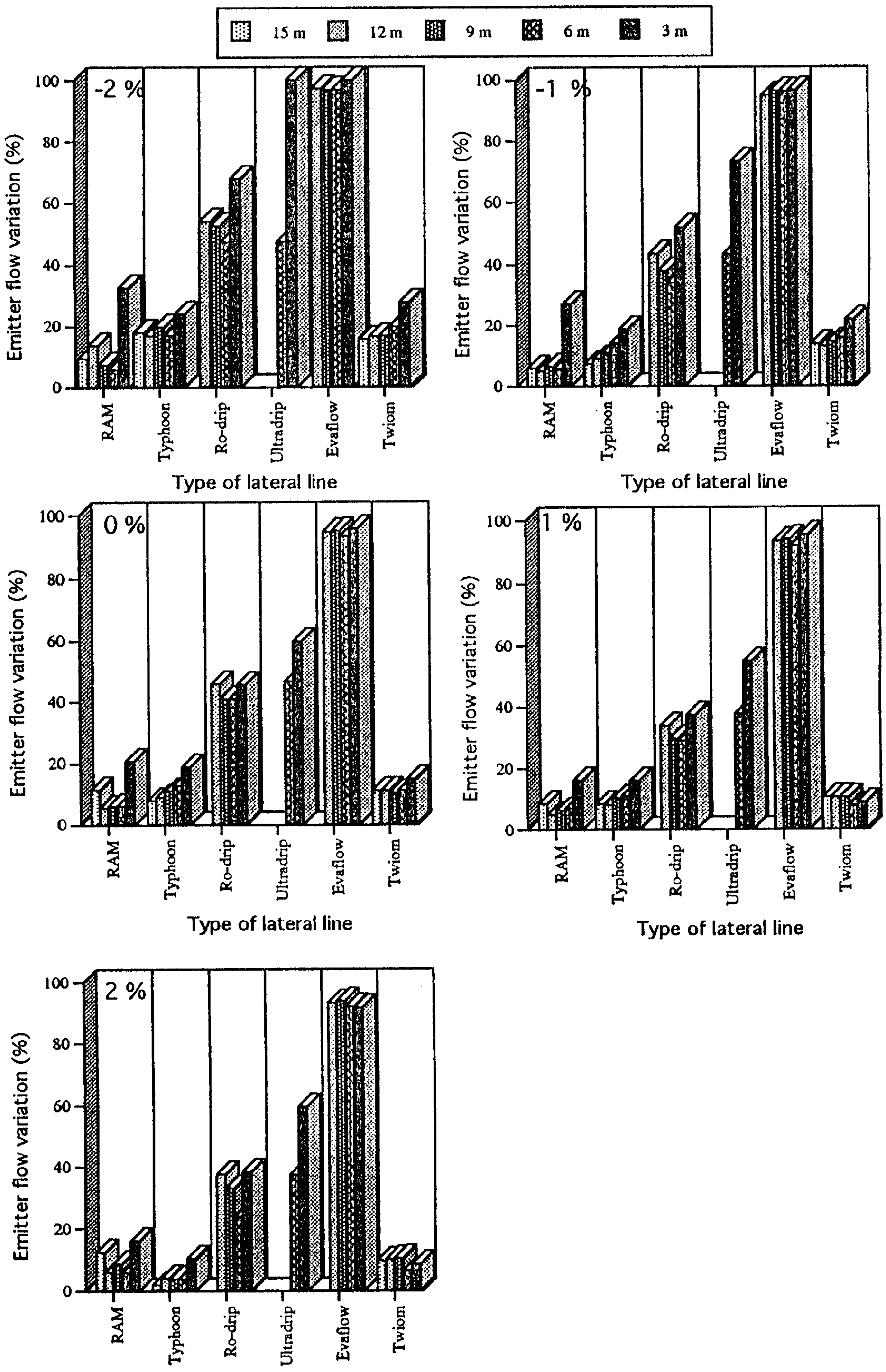


Fig. (4-15): Effect of type and slope of lateral line on emitter flow rate variation at different operating pressure head.

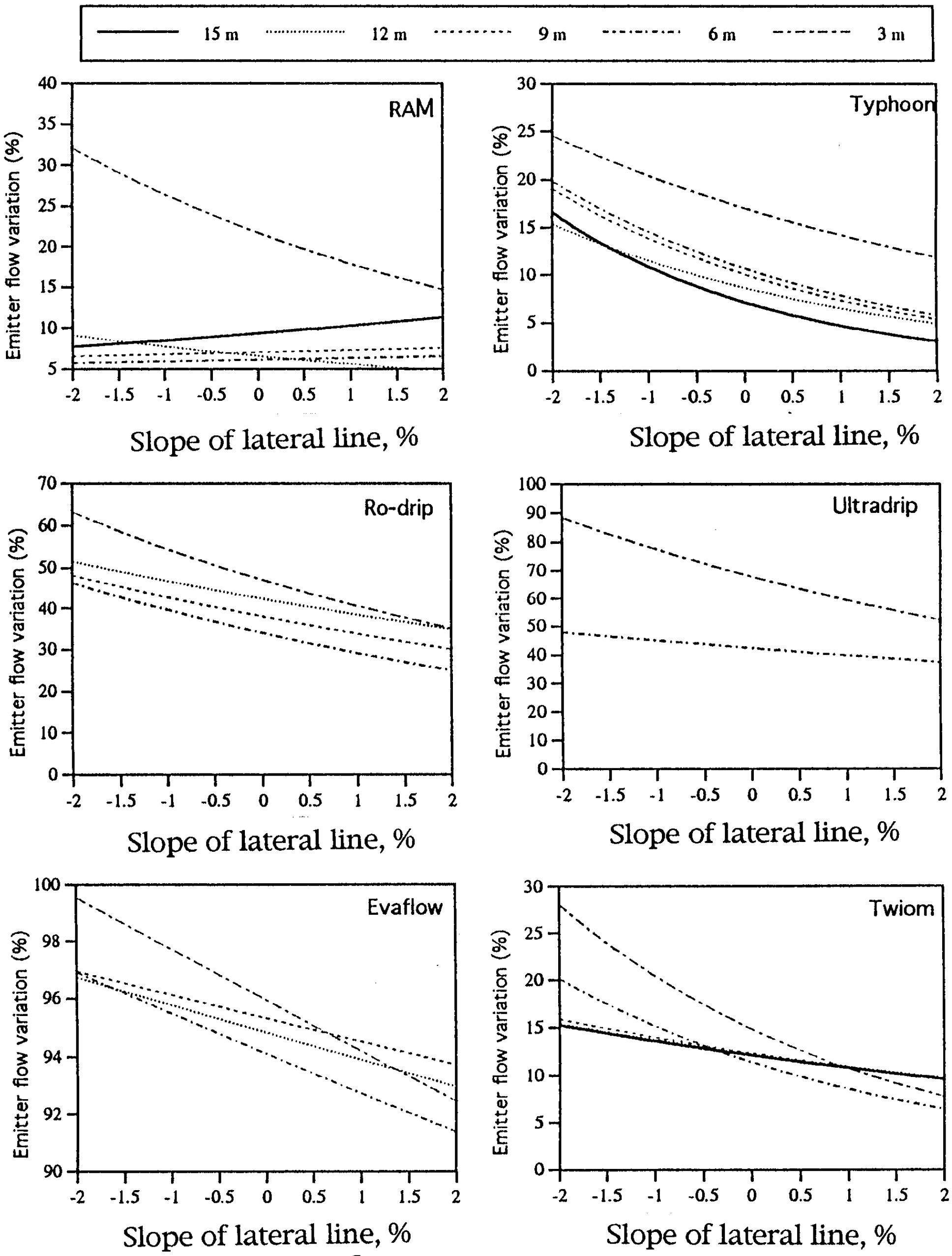


Fig. (4-16): Effect of slope and type of lateral line and inlet pressure head on emitter flow variation.

Table (4-2): Effect of type and slope of lateral line and inlet pressure head on system performance.

| | | | | (3*6*2*5) | | |
|---|---|---|---|---|---|---|
| Factores | | Flow rate variation (%) | Pressure variation (%) | Distribution of uniformity (%) | Pressure head losses (m) | Coefficient of uniformity (%) |
| Lateral line | RAM | 14.37 | 75.12 | 93.94 | 3.07 | 95.12 |
| | Typhoon | 14.73 | 43.17 | 93.91 | 1.76 | 96.00 |
| | Ro-drip | 41.64 | 41.54 | 82.79 | 1.68 | 88.78 |
| | Ultradrip | 56.05 | 45.83 | 73.43 | 1.96 | 76.48 |
| | Evaflow | 95.03 | 88.29 | 24.57 | 3.99 | 23.35 |
| | Twiom | 14.36 | 54.86 | 94.92 | 2.29 | 96.11 |
| L.S.D. | 0.05 | 0.94 | 0.54 | 0.62 | 0.05 | 0.74 |
| | 0.01 | 1.29 | 0.74 | 0.85 | 0.07 | 1.02 |
| Inlet pressure head (m) | 6 | 33.65 | 47.49 | 80.75 | 2.85 | 80.43 |
| | 3 | 45.07 | 68.78 | 73.77 | 2.06 | 78.19 |
| L.S.D. | 0.05 | 0.35 | 0.33 | 0.40 | 0.03 | 0.49 |
| | 0.01 | 0.48 | 0.46 | 0.56 | 0.04 | 0.68 |
| Slope of lateral line (%) | - 2 | 48.85 | 68.90 | 69.31 | 2.89 | 72.61 |
| | - 1 | 41.65 | 65.14 | 75.57 | 2.73 | 77.28 |
| | 0 | 38.90 | 57.75 | 78.74 | 2.44 | 80.65 |
| | 1 | 34.49 | 53.01 | 81.16 | 2.26 | 82.84 |
| | 2 | 32.92 | 45.89 | 81.52 | 1.97 | 83.17 |
| L.S.D. | 0.05 | 0.67 | 0.45 | 0.50 | 0.03 | 0.44 |
| | 0.01 | 0.89 | 0.59 | 0.66 | 0.04 | 0.59 |
| | | | | (3*5*4*5) | | |
| Lateral line | RAM | 10.74 | 53.00 | 95.44 | 3.12 | 96.59 |
| | Typhoon | 12.55 | 30.59 | 94.92 | 1.80 | 96.75 |
| | Ro-drip | 41.26 | 30.76 | 83.86 | 1.87 | 88.03 |
| | Evaflow | 95.05 | 88.63 | 24.48 | 6.66 | 13.94 |
| | Twiom | 13.42 | 43.72 | 95.20 | 2.84 | 96.38 |
| L.S.D. | 0.05 | 0.64 | 0.36 | 0.39 | 0.03 | 0.30 |
| | 0.01 | 0.92 | 0.53 | 0.57 | 0.04 | 0.44 |
| Inlet pressure head (m) | 12 | 33.36 | 35.41 | 79.35 | 4.25 | 75.96 |
| | 9 | 33.01 | 40.76 | 79.72 | 3.67 | 77.64 |
| | 6 | 31.88 | 49.22 | 80.31 | 2.95 | 79.77 |
| | 3 | 40.17 | 71.97 | 75.74 | 2.16 | 79.98 |
| L.S.D. | 0.05 | 0.36 | 0.34 | 0.23 | 0.04 | 0.22 |
| | 0.01 | 0.49 | 0.46 | 0.31 | 0.06 | 0.29 |
| Slope of lateral line (%) | - 2 | 41.51 | 56.02 | 74.58 | 3.63 | 74.57 |
| | - 1 | 35.77 | 53.06 | 77.82 | 3.44 | 77.50 |
| | 0 | 34.54 | 49.07 | 79.48 | 3.24 | 78.78 |
| | 1 | 31.22 | 46.33 | 81.08 | 3.10 | 80.44 |
| | 2 | 29.99 | 42.23 | 80.94 | 2.87 | 80.39 |
| L.S.D. | 0.05 | 0.31 | 0.32 | 0.24 | 0.03 | 0.20 |
| | 0.01 | 0.40 | 0.42 | 0.32 | 0.04 | 0.26 |

Table (4-2): Continue

(3*3*5*5)

| Factores | | Flow rate variation (%) | Pressure variation (%) | Distribution of uniformity (%) | Pressure head losses (m) | Coefficient of uniformity (%) |
|---|---|---|---|---|---|---|
| Lateral line | RAM | 10.52 | 46.10 | 95.63 | 3.05 | 96.78 |
| | Typhoon | 11.80 | 27.09 | 95.28 | 1.83 | 97.00 |
| | Twiom | 13.19 | 40.56 | 95.20 | 3.11 | 96.38 |
| L.S.D. | 0.01 | 0.91 | 0.33 | 0.29 | 0.04 | 0.16 |
| | 0.05 | 1.51 | 0.55 | 0.47 | 0.07 | 0.26 |
| Inlet pressure head (m) | 15 | 10.23 | 19.83 | 96.10 | 2.98 | 97.31 |
| | 12 | 9.67 | 23.63 | 96.22 | 2.84 | 97.47 |
| | 9 | 10.31 | 30.68 | 96.01 | 2.76 | 97.34 |
| | 6 | 10.09 | 42.56 | 96.24 | 2.55 | 97.41 |
| | 3 | 18.88 | 72.87 | 92.27 | 2.19 | 94.08 |
| L.S.D. | 0.01 | 0.45 | 0.50 | 0.14 | 0.07 | 0.10 |
| | 0.05 | 0.62 | 0.68 | 0.19 | 0.09 | 0.13 |
| Slope of lateral line (%) | -2 | 17.37 | 43.36 | 93.36 | 2.99 | 95.14 |
| | -1 | 12.72 | 41.08 | 94.81 | 2.82 | 96.28 |
| | 0 | 11.26 | 37.60 | 95.54 | 2.64 | 96.88 |
| | 1 | 9.82 | 35.13 | 96.27 | 2.51 | 97.41 |
| | 2 | 8.02 | 32.41 | 96.87 | 2.36 | 97.89 |
| L.S.D. | 0.01 | 0.34 | 0.42 | 0.12 | 0.06 | 0.08 |
| | 0.05 | 0.44 | 0.56 | 0.16 | 0.07 | 0.11 |

Table (4-3):Effect of interaction between type of lateral line and inlet pressure head on flow rate variation (%).

(3*6*2*5)

| Lateral line | Inlet pressure head (m) | |
|---|---|---|
| | 6 | 3 |
| RAM | 6.14 | 22.59 |
| Typhoon | 11.82 | 17.64 |
| Ro-drip | 35.04 | 48.24 |
| Ultradrip | 42.52 | 69.58 |
| Evaflow | 94.11 | 95.96 |
| Twiom | 12.30 | 16.42 |
| L.S.D. (5%)= | 0.85 | |
| (1%) = | 1.19 | |

(3*5*4*5)

| Lateral line | Inlet pressure head (m) | | | |
|---|---|---|---|---|
| | 12 | 9 | 6 | 3 |
| RAM | 7.14 | 7.08 | 6.14 | 22.59 |
| Typhoon | 9.48 | 11.28 | 11.82 | 17.64 |
| Ro-drip | 42.96 | 38.79 | 35.04 | 48.24 |
| Evaflow | 94.83 | 95.32 | 94.11 | 95.96 |
| Twiom | 12.40 | 12.57 | 12.30 | 16.42 |
| L.S.D. (5%)= | 0.81 | | | |
| (1%)= | 1.09 | | | |

(3*3*5*5)

| Lateral lines | Inlet pressure head (m) | | | | |
|---|---|---|---|---|---|
| | 15 | 12 | 9 | 6 | 3 |
| RAM | 9.63 | 7.14 | 7.08 | 6.14 | 22.59 |
| Typhoon | 8.80 | 9.48 | 11.28 | 11.82 | 17.64 |
| Twiom | 12.25 | 12.40 | 12.57 | 12.30 | 16.42 |
| L.S.D. (5%)= | 0.79 | | | | |
| (1%)= | 1.07 | | | | |

Table (4-4): Effect of interaction between type of lateral line and inlet pressure head on flow rate variation (%).

| Lateral line | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| **(3*6*2*5)** | | | | | |
| RAM | 19.21 | 16.52 | 13.43 | 11.68 | 11.01 |
| Typhoon | 20.37 | 16.52 | 15.86 | 13.67 | 7.23 |
| Ro-drip | 57.55 | 43.05 | 43.35 | 33.09 | 31.14 |
| Ultradrip | 73.78 | 58.37 | 53.20 | 46.38 | 48.52 |
| Evaflow | 98.43 | 96.51 | 94.55 | 93.74 | 91.93 |
| Twiom | 23.75 | 18.93 | 13.04 | 8.39 | 7.68 |
| L.S.D. (5%) = | 1.64 | | | | |
| (1%) = | 2.17 | | | | |
| **(3*5*4*5)** | | | | | |
| RAM | 14.87 | 11.18 | 9.65 | 8.75 | 9.24 |
| Typhoon | 19.30 | 13.30 | 12.94 | 11.55 | 5.69 |
| Ro-drip | 55.42 | 41.87 | 43.35 | 32.44 | 33.20 |
| Evaflow | 97.80 | 96.07 | 94.78 | 93.82 | 92.79 |
| Twiom | 20.18 | 16.41 | 11.98 | 9.51 | 9.02 |
| L.S.D. (5%)= | 0.68 | | | | |
| (1%)= | 0.90 | | | | |
| **(3*3*5*5)** | | | | | |
| RAM | 13.79 | 10.14 | 10.03 | 8.74 | 9.90 |
| Typhoon | 19.03 | 12.13 | 11.94 | 10.96 | 4.96 |
| Twiom | 19.28 | 15.89 | 11.81 | 9.76 | 9.19 |
| L.S.D. (5%)= | 0.58 | | | | |
| (1%)= | 0.77 | | | | |

Table (4-5): Effect of interaction between slope of lateral line and inlet pressure head on flow rate variation (%).

| Inlet pressure head (m) | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| **(3*6*2*5)** | | | | | |
| 6 | 39.00 | 34.93 | 35.20 | 30.79 | 28.36 |
| 3 | 58.70 | 48.37 | 42.61 | 38.19 | 37.48 |
| L.S.D. (5%) = | 0.95 | | | | |
| (1%) = | 1.25 | | | | |
| **(3*5*4*5)** | | | | | |
| 12 | 39.71 | 33.15 | 33.30 | 30.35 | 30.29 |
| 9 | 38.62 | 33.31 | 32.77 | 30.29 | 30.06 |
| 6 | 37.29 | 33.25 | 32.93 | 29.39 | 26.55 |
| 3 | 50.44 | 43.36 | 39.16 | 34.84 | 33.05 |
| L.S.D. (5%)= | 0.61 | | | | |
| (1%)= | 0.80 | | | | |
| **(3*3*5*5)** | | | | | |
| 15 | 14.36 | 9.07 | 10.20 | 9.35 | 8.14 |
| 12 | 15.71 | 9.11 | 8.61 | 8.08 | 6.85 |
| 9 | 14.54 | 10.77 | 9.26 | 9.18 | 7.80 |
| 6 | 14.06 | 11.96 | 10.10 | 8.72 | 5.59 |
| 3 | 28.15 | 22.68 | 18.11 | 13.77 | 11.70 |
| L.S.D. (5%)= | 0.75 | | | | |
| (1%)= | 1.00 | | | | |

Table 4-6: Effect of interaction between type and slope of lateral line and inlet pressure head on flow rate variation (%).

| Inlet pressure head (m) | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| (3*6*2*5) | | | | | |
| | | | RAM | | |
| 6 | 5.70 | 5.77 | 6.14 | 7.10 | 6.01 |
| 3 | 32.71 | 27.28 | 20.72 | 16.25 | 16.01 |
| | | | Typhoon | | |
| 6 | 16.78 | 14.17 | 12.90 | 11.23 | 4.02 |
| 3 | 23.96 | 18.87 | 18.82 | 16.12 | 10.44 |
| | | | Ro-drip | | |
| 6 | 47.37 | 34.10 | 40.98 | 28.83 | 23.90 |
| 3 | 67.73 | 51.99 | 45.72 | 37.36 | 38.37 |
| | | | Ultradrip | | |
| 6 | 47.56 | 43.30 | 46.54 | 37.79 | 37.40 |
| 3 | 100.00 | 73.43 | 59.86 | 54.97 | 59.65 |
| | | | Evaflow | | |
| 6 | 96.87 | 96.26 | 93.34 | 91.98 | 92.08 |
| 3 | 100.00 | 96.76 | 95.76 | 95.51 | 91.77 |
| | | | Twiom | | |
| 6 | 19.71 | 15.95 | 11.27 | 7.83 | 6.73 |
| 3 | 27.79 | 21.91 | 14.80 | 8.94 | 8.64 |
| L.S.D. (5%) = | 2.32 | | | | |
| (1%) = | 3.07 | | | | |
| (3*5*4*5) | | | | | |
| | | | RAM | | |
| 12 | 13.77 | 5.12 | 5.50 | 5.20 | 6.10 |
| 9 | 7.31 | 6.57 | 6.23 | 6.45 | 8.86 |
| 6 | 5.70 | 5.77 | 6.14 | 7.10 | 6.01 |
| 3 | 32.71 | 27.28 | 20.72 | 16.25 | 16.01 |
| | | | Typhoon | | |
| 12 | 16.78 | 9.18 | 8.98 | 8.24 | 4.22 |
| 9 | 19.69 | 10.98 | 11.05 | 10.60 | 4.07 |
| 6 | 16.78 | 14.17 | 12.90 | 11.23 | 4.02 |
| 3 | 23.96 | 18.87 | 18.82 | 16.12 | 10.44 |
| | | | Ro-drip | | |
| 12 | 54.01 | 43.49 | 45.80 | 33.94 | 37.53 |
| 9 | 52.56 | 37.88 | 40.89 | 29.65 | 32.99 |
| 6 | 47.37 | 34.10 | 40.98 | 28.83 | 23.90 |
| 3 | 67.73 | 51.99 | 45.72 | 37.36 | 38.37 |
| | | | Evaflow | | |
| 12 | 97.43 | 94.92 | 94.86 | 93.56 | 93.38 |
| 9 | 96.89 | 96.35 | 95.17 | 94.24 | 93.92 |
| 6 | 96.87 | 96.26 | 93.34 | 91.98 | 92.08 |
| 3 | 100.00 | 96.76 | 95.76 | 95.51 | 91.77 |
| | | | Twiom | | |
| 12 | 16.58 | 13.02 | 11.36 | 10.79 | 10.23 |
| 9 | 16.63 | 14.75 | 10.50 | 10.50 | 10.48 |
| 6 | 19.71 | 15.95 | 11.27 | 7.83 | 6.73 |
| 3 | 27.79 | 21.91 | 14.80 | 8.94 | 8.64 |
| L.S.D. (5%)= | 1.37 | | | | |
| (1%)= | 1.80 | | | | |

Table 4-6:Continue

(3*3*5*5)

| Inlet pressure head m | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | RAM | | |
| 15 | 9.44 | 5.94 | 11.54 | 8.71 | 12.53 |
| 12 | 13.77 | 5.12 | 5.50 | 5.20 | 6.10 |
| 9 | 7.31 | 6.57 | 6.23 | 6.45 | 8.86 |
| 6 | 5.70 | 5.77 | 6.14 | 7.10 | 6.01 |
| 3 | 32.71 | 27.28 | 20.72 | 16.25 | 16.01 |
| | | | Typhoon | | |
| 15 | 17.96 | 7.46 | 7.94 | 8.60 | 2.03 |
| 12 | 16.78 | 9.18 | 8.98 | 8.24 | 4.22 |
| 9 | 19.69 | 10.98 | 11.05 | 10.60 | 4.07 |
| 6 | 16.78 | 14.17 | 12.90 | 11.23 | 4.02 |
| 3 | 23.96 | 18.87 | 18.82 | 16.12 | 10.44 |
| | | | Twiom | | |
| 15 | 15.68 | 13.82 | 11.13 | 10.72 | 9.88 |
| 12 | 16.58 | 13.02 | 11.36 | 10.79 | 10.23 |
| 9 | 16.63 | 14.75 | 10.50 | 10.50 | 10.48 |
| 6 | 19.71 | 15.95 | 11.27 | 7.83 | 6.73 |
| 3 | 27.79 | 21.91 | 14.80 | 8.94 | 8.64 |
| L.S.D. (5%)= | 1.30 | | | | |
| (1%)= | 1.72 | | | | |

### 4.6 Head variation ($h_{var}$)

The pressure profile shows the pressure variation from the operating pressure along the lateral line. The pressure variation along the lateral line can be determined simply by a linear combination of energy drop by friction and energy gained (or lost) by slopes. It is affected by uniformity of emitter flow along the lateral line.

The statistical analysis indicated that the above mentioned independent factors such as type of lateral line, operating pressure head and slope of lateral line had a highly significant effect on the head variation (Table 5-3 in Appendix). Figures (4-17 to 4-19 ) and Tables (4-2, 4-7 to.4-10) testified the effect of type and slope of lateral line and operating head and their interaction on pressure head variation. The head variations were 75.12, 43.17, 41.54, 45.83, 88.29, and 54.86 % for the RAM, Typhoon, Ro-drip, Ultradrip, Evaflow, and Twiom respectively (Table 4-2). Decreasing both operating head and slope of lateral line increased the head variations. The percentages of head variations were 72.87, 42.56, 30.68, 23.63, and 19.83 for operating heads 3, 6, 9, 12, 15 m respectively (Table 4-2). They were 56.09, 53.09, 48.14, 45.16, and 40.18 % for slope -2, -1, 0 , 1, 2 % respectively (the values were calculated as the same with emitter flow rate variation in Tables (4-2). The best result was obtained from the Typhoon at 15 m operating head and 2 % slope (Table 4-10). The RAM was the worst lateral line during operation under 3 m head and -2 % slope. As the variations of emitters flow rate increased the variation of heads increased.

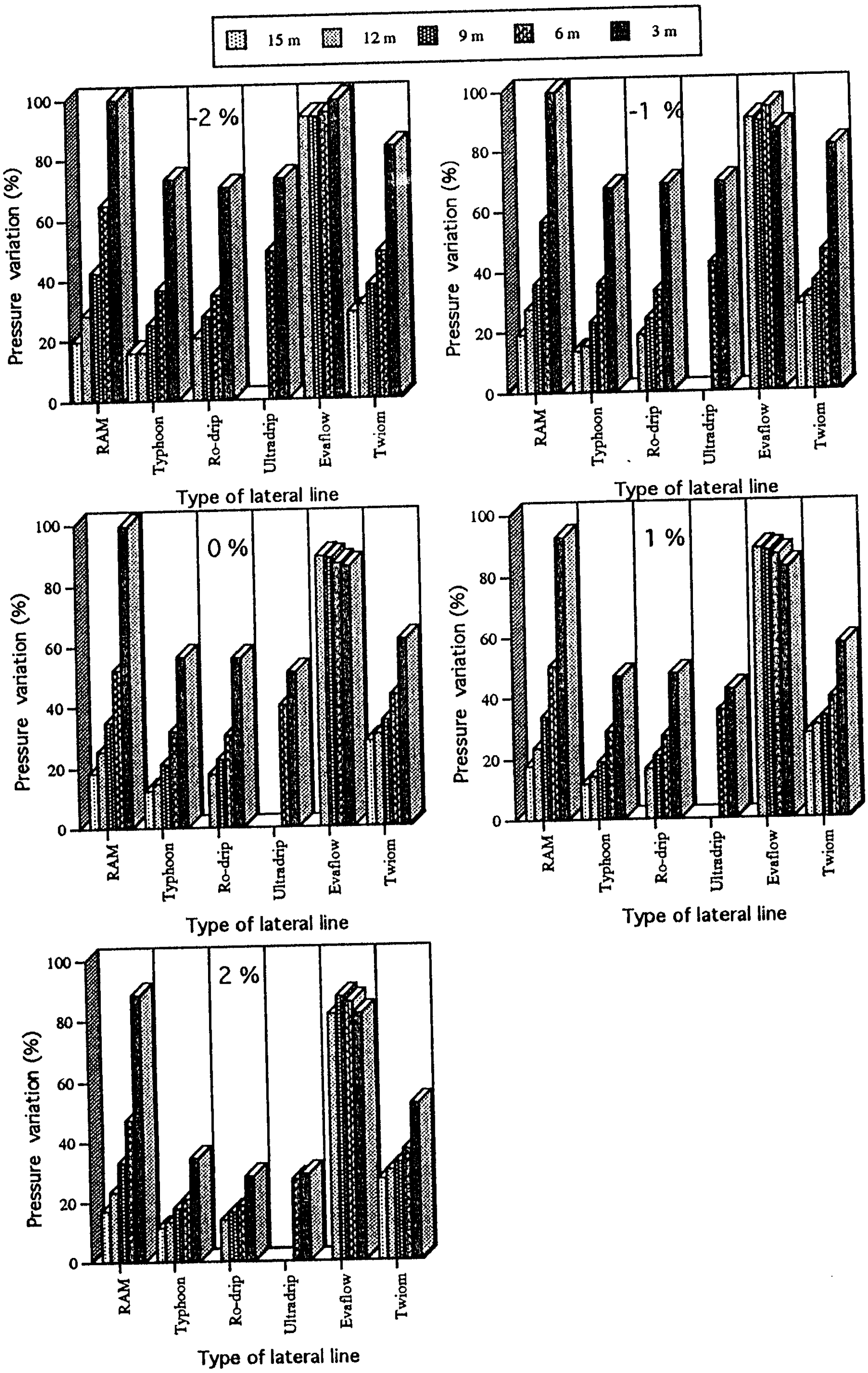


Fig. (4-17): Effect of type and slope of lateral line on pressure head variation at different operating pressure head.

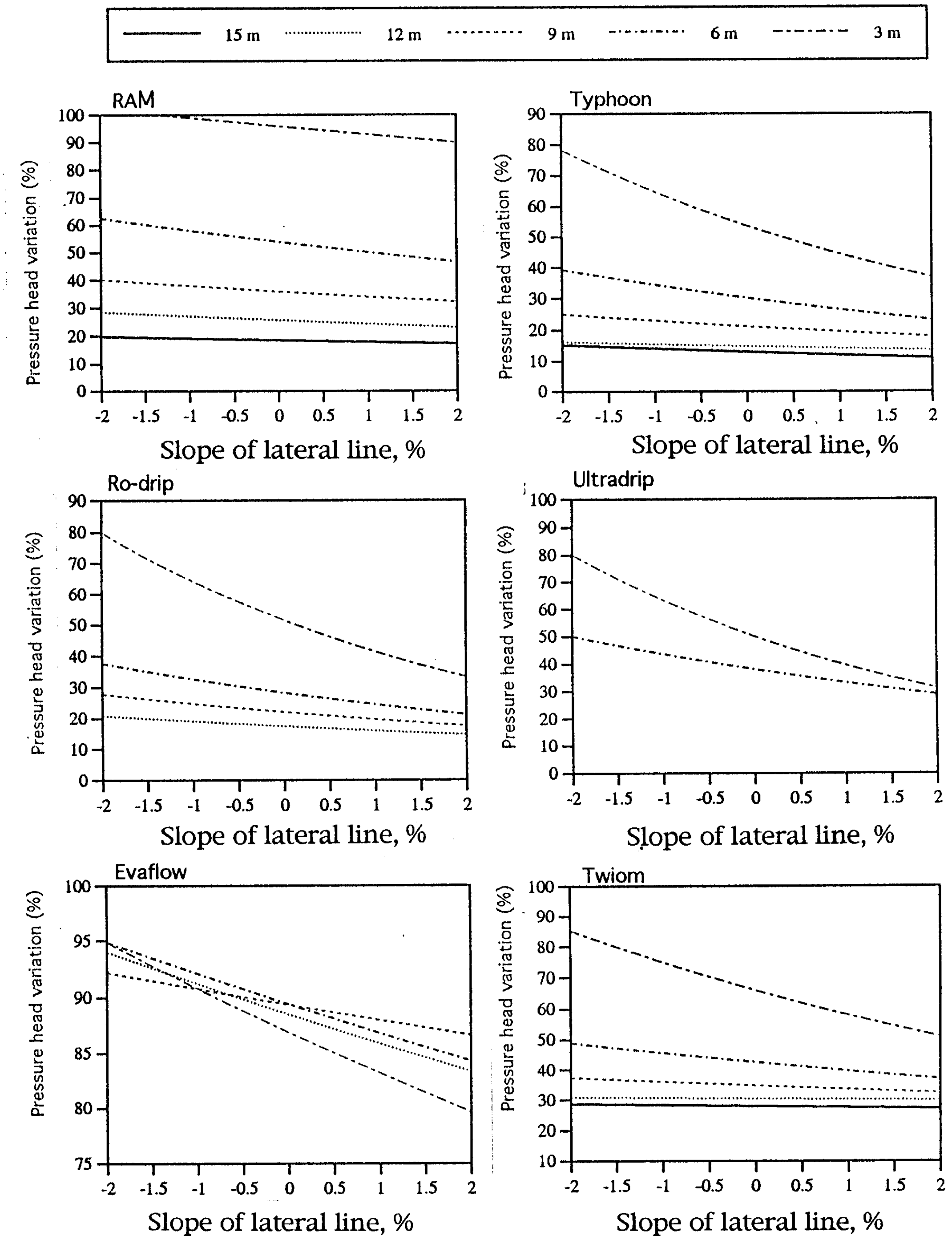


Fig. (4-18): Effect of slope and type of lateral line and inlet pressure head on pressure head variation.

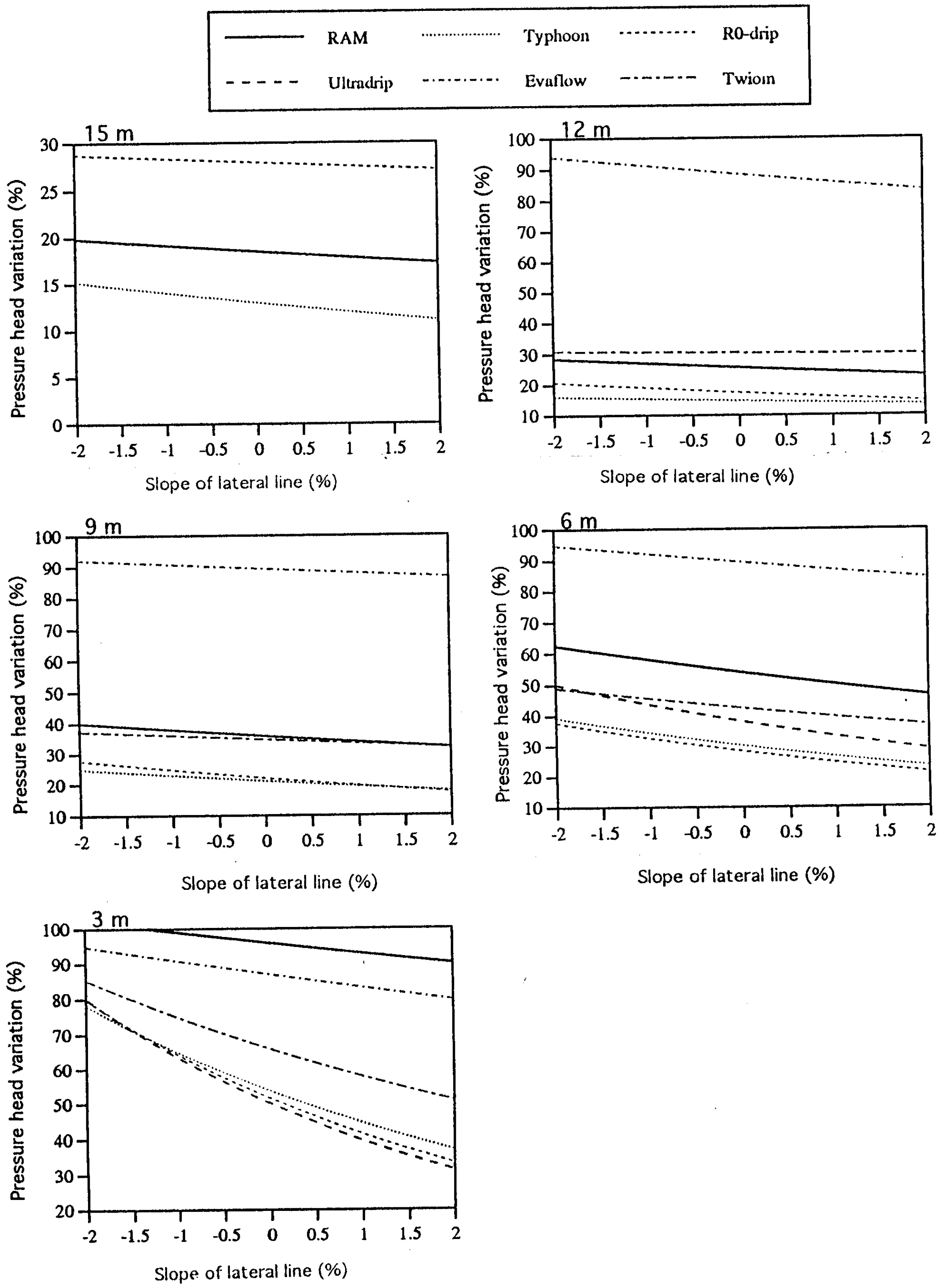


Fig. (4-19):Effect of type and slope of lateral line and inlet pressure head on pressure head variation.

Table (4-7):Effect of interaction between type of lateral line and inlet pressure head on pressure variation (%).

(3*6*2*5)

| Lateral line | Inlet pressure head (m) 6 | 3 |
|---|---|---|
| RAM | 54.25 | 95.99 |
| Typhoon | 30.74 | 55.60 |
| Ro-drip | 28.93 | 54.16 |
| Ultradrip | 38.81 | 52.85 |
| Evaflow | 89.50 | 87.08 |
| Twiom | 42.70 | 67.03 |
| L.S.D. (5%) = | 0.80 | |
| (1%) = | 1.12 | |

(3*5*4*5)

| Lateral line | Inlet pressure head (m) | | | |
|---|---|---|---|---|
| | 12 | 9 | 6 | 3 |
| RAM | 25.72 | 36.02 | 54.25 | 95.99 |
| Typhoon | 14.77 | 21.27 | 30.74 | 55.60 |
| Ro-drip | 17.59 | 22.37 | 28.93 | 54.16 |
| Evaflow | 88.58 | 89.38 | 89.50 | 87.08 |
| Twiom | 30.41 | 34.75 | 42.70 | 67.03 |
| L.S.D. (5%)= | 0.76 | | | |
| (1%)= | 1.03 | | | |

(3*3*5*5)

| Lateral lines | Inlet pressure head (m) | | | | |
|---|---|---|---|---|---|
| | 15 | 12 | 9 | 6 | 3 |
| RAM | 18.51 | 25.72 | 36.02 | 54.25 | 95.99 |
| Typhoon | 13.05 | 14.77 | 21.27 | 30.74 | 55.60 |
| Twiom | 27.94 | 30.41 | 34.75 | 42.70 | 67.03 |
| L.S.D. (5%)= | 0.87 | | | | |
| (1%)= | 1.18 | | | | |

Table (4-8): Effect of interaction between Type of lateral line and inlet pressure head on pressure variation (%).

(3*6*2*5)

| Lateral line | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | -2 | -1 | 0 | 1 | 2 |
| RAM | 82.33 | 78.14 | 75.64 | 71.57 | 67.93 |
| Typhoon | 54.76 | 51.65 | 43.98 | 37.76 | 27.71 |
| Ro-drip | 52.41 | 51.14 | 43.24 | 37.42 | 23.51 |
| Ultradrip | 60.99 | 55.84 | 45.48 | 38.85 | 28.00 |
| Evaflow | 97.01 | 90.51 | 85.98 | 84.28 | 83.67 |
| Twiom | 65.90 | 63.57 | 52.17 | 48.18 | 44.50 |
| L.S.D. (5%) = | 1.09 | | | | |
| (1%) = | 1.45 | | | | |

(3*5*4*5)

| Lateral line | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| RAM | 58.84 | 54.91 | 52.94 | 50.21 | 48.07 |
| Typhoon | 37.63 | 35.42 | 31.00 | 27.23 | 21.70 |
| Ro-drip | 38.24 | 36.30 | 31.70 | 28.14 | 19.42 |
| Evaflow | 95.32 | 90.27 | 87.33 | 86.17 | 84.08 |
| Twiom | 50.07 | 48.39 | 42.37 | 39.91 | 37.86 |
| L.S.D. (5%)= | 0.72 | | | | |
| (1%)= | 0.95 | | | | |

(3*3*5*5)

| Lateral line | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| RAM | 51.02 | 47.80 | 46.02 | 43.76 | 41.89 |
| Typhoon | 33.27 | 31.08 | 27.28 | 24.17 | 19.64 |
| Twiom | 45.80 | 44.37 | 39.50 | 37.46 | 35.70 |
| L.S.D. (5%)= | 0.73 | | | | |
| (1%)= | 0.96 | | | | |

Table (4-9): Effect of interaction between slope of lateral line and inlet pressure head on pressure variation (%).

| Inlet pressure head (m) | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | (3*6*2*5) | | |
| 6 | 54.72 | 51.41 | 47.25 | 44.59 | 39.46 |
| 3 | 83.07 | 78.87 | 68.24 | 61.43 | 52.32 |
| L.S.D. (5%) = | 0.63 | | | | |
| (1%) = | 0.84 | | | | |
| | | | (3*5*4*5) | | |
| 12 | 37.89 | 36.60 | 35.48 | 34.67 | 32.42 |
| 9 | 45.23 | 41.63 | 40.38 | 38.98 | 37.56 |
| 6 | 55.87 | 53.21 | 48.70 | 46.42 | 41.93 |
| 3 | 85.10 | 80.79 | 71.70 | 65.27 | 57.00 |
| L.S.D. (5%)= | 0.64 | | | | |
| (1%)= | 0.85 | | | | |
| | | | (3*3*5*5) | | |
| 15 | 21.42 | 20.45 | 19.59 | 19.16 | 18.54 |
| 12 | 25.09 | 24.54 | 23.57 | 22.75 | 22.20 |
| 9 | 34.97 | 31.52 | 30.30 | 28.72 | 27.88 |
| 6 | 49.88 | 46.14 | 42.19 | 39.53 | 35.08 |
| 3 | 85.44 | 82.77 | 72.34 | 65.47 | 58.35 |
| L.S.D. (5%)= | 0.94 | | | | |
| (1%)= | 1.24 | | | | |

Table (4-10): Effect of interaction between type and slope of lateral line and inlet pressure head on pressure variation (%).

(3*6*2*5)

| Inlet pressure head (m) | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | RAM | | |
| 6 | 64.73 | 56.56 | 52.07 | 50.54 | 47.37 |
| 3 | 99.93 | 99.72 | 99.20 | 92.60 | 88.50 |
| | | | Typhoon | | |
| 6 | 36.56 | 35.76 | 31.57 | 28.73 | 21.09 |
| 3 | 72.96 | 67.54 | 56.39 | 46.79 | 34.33 |
| | | | Ro-drip | | |
| 6 | 34.62 | 33.55 | 30.50 | 27.19 | 18.78 |
| 3 | 70.20 | 68.73 | 55.98 | 47.65 | 28.24 |
| | | | Ultradrip | | |
| 6 | 49.02 | 42.43 | 40.02 | 35.49 | 27.10 |
| 3 | 72.96 | 69.24 | 50.93 | 42.22 | 28.90 |
| | | | Evaflow | | |
| 6 | 95.06 | 94.09 | 86.45 | 86.29 | 85.61 |
| 3 | 98.97 | 86.92 | 85.51 | 82.26 | 81.73 |
| | | | Twiom | | |
| 6 | 48.37 | 46.08 | 42.92 | 39.32 | 36.80 |
| 3 | 83.42 | 81.05 | 61.42 | 57.03 | 52.21 |

L.S.D. (5%) = 1.55
(1%) = 2.05

Table (4-10) :Continue

| Inlet pressure head, m | Slope of lateral line, % -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| (3*5*4*5) | | | | | |
| | | | RAM | | |
| 12 | 28.28 | 27.62 | 25.52 | 23.82 | 23.36 |
| 9 | 42.43 | 35.75 | 34.94 | 33.89 | 33.07 |
| 6 | 64.73 | 56.56 | 52.07 | 50.54 | 47.37 |
| 3 | 99.93 | 99.72 | 99.20 | 92.60 | 88.50 |
| | | | Typhoon | | |
| 12 | 16.01 | 15.41 | 14.88 | 14.24 | 13.29 |
| 9 | 24.98 | 22.98 | 21.15 | 19.14 | 18.08 |
| 6 | 36.56 | 35.76 | 31.57 | 28.73 | 21.09 |
| 3 | 72.96 | 67.54 | 56.39 | 46.79 | 34.33 |
| | | | Ro-drip | | |
| 12 | 20.56 | 18.84 | 17.79 | 16.77 | 13.97 |
| 9 | 27.60 | 24.10 | 22.51 | 20.97 | 16.67 |
| 6 | 34.62 | 33.55 | 30.50 | 27.19 | 18.78 |
| 3 | 70.20 | 68.73 | 55.98 | 47.65 | 28.24 |
| | | | Evaflow | | |
| 12 | 93.60 | 90.56 | 88.90 | 88.34 | 81.51 |
| 9 | 93.64 | 89.50 | 88.47 | 87.79 | 87.47 |
| 6 | 95.06 | 94.09 | 86.45 | 86.29 | 85.61 |
| 3 | 98.97 | 86.92 | 85.51 | 82.26 | 81.73 |
| | | | Twiom | | |
| 12 | 30.99 | 30.59 | 30.31 | 30.18 | 29.95 |
| 9 | 37.51 | 35.84 | 34.81 | 33.12 | 32.49 |
| 6 | 48.37 | 46.08 | 42.92 | 39.32 | 36.80 |
| 3 | 83.42 | 81.05 | 61.42 | 57.03 | 52.21 |
| L.S.D. (5%)= | 1.44 | | | | |
| (1%)= | 1.89 | | | | |
| (3*3*5*5) | | | | | |
| | | | RAM | | |
| 15 | 19.73 | 19.35 | 18.37 | 17.93 | 17.17 |
| 12 | 28.28 | 27.62 | 25.52 | 23.82 | 23.36 |
| 9 | 42.43 | 35.75 | 34.94 | 33.89 | 33.07 |
| 6 | 64.73 | 56.56 | 52.07 | 50.54 | 47.37 |
| 3 | 99.93 | 99.72 | 99.20 | 92.60 | 88.50 |
| | | | Typhoon | | |
| 15 | 15.82 | 13.71 | 12.39 | 11.93 | 11.40 |
| 12 | 16.01 | 15.41 | 14.88 | 14.24 | 13.29 |
| 9 | 24.98 | 22.98 | 21.15 | 19.14 | 18.08 |
| 6 | 36.56 | 35.76 | 31.57 | 28.73 | 21.09 |
| 3 | 72.96 | 67.54 | 56.39 | 46.79 | 34.33 |
| | | | Twiom | | |
| 15 | 28.71 | 28.28 | 28.02 | 27.64 | 27.04 |
| 12 | 30.99 | 30.59 | 30.31 | 30.18 | 29.95 |
| 9 | 37.51 | 35.84 | 34.81 | 33.12 | 32.49 |
| 6 | 48.37 | 46.08 | 42.92 | 39.32 | 36.80 |
| 3 | 83.42 | 81.05 | 61.42 | 57.03 | 52.21 |
| L.S.D. (5%)= | 1.63 | | | | |
| (1%)= | 2.15 | | | | |

## 4.7 Distribution uniformity

For trickle irrigation, depth of applied water is directly related to flow rate when each emitter covers an equal area and is pressurized for the same duration. As a performance measure, distribution uniformity can be related to yields when the remaining 75% of the field is adequately irrigated, yield response to under irrigation is linear, and over irrigation does not have a detrimental effect on crop yield.

Tables (4-2, 4-11 to 4-14) and Figures (4-20 to 4-24) show the results of distribution uniformity calculations for various inlet pressure heads and slopes of lateral line.

The statistical analysis proved that the $DU$ was significantly affected by all independent factors (Table 4 in the Appendix). It increased by increasing both operating head and slope of lateral line. It increased by the following ratios: 4.16, 4.28, 4.06, and 4.30 for operating heads 15, 12, 9, and 6 m respectively compared with 3 m operating head of $DU$ equals 92.27 % (see Table 4-2).

The increasing ratios of $DU$ were 4.49, 8.19, 8.97, and 9.31 for slopes -1, 0, 1, and 2% respectively compared with -2 % slope where its value was 79.08% (each value is calculated in the same way as flow rate variation in Table (4-2). Also, $DU$ values were 93.94, 93.91, 82.79, 73.43, 24.57, and 94.92 % for the following lateral lines: RAM, Typhoon, Ro-drip, Ultradrip, Evaflow , and Twiom respectively (Table 4-2).

Figures (4-25 to 4-29) show the relationship between the total average and lowest 1/4 of emitter flow rate. The shadow part from the curve indicates the excessive water loss which will occur if adequate irrigation is supplied to all areas. The highest water loss value was in the Evaflow lateral line at 12 m operating pressure head (Fig. 4-26). The Typhoon and Twiom gave the lowest values for water losses.

Table (4-11):Effect of interaction between type of lateral line and inlet pressure head on distribution of uniformity (%).

(3*6*2*5)

| Lateral line | Inlet pressure head (m) | |
|---|---|---|
| | 6 | 3 |
| RAM | 97.50 | 90.38 |
| Typhoon | 95.51 | 92.32 |
| Ro-drip | 86.06 | 79.52 |
| Ultradrip | 82.93 | 63.93 |
| Evaflow | 26.78 | 22.36 |
| Twiom | 95.72 | 94.12 |
| L.S.D. (5%) = | 0.99 | |
| (1%) = | 1.38 | |

(3*5*4*5)

| Lateral line | Inlet pressure head (m) | | | |
|---|---|---|---|---|
| | 12 | 9 | 6 | 3 |
| RAM | 97.03 | 96.85 | 97.50 | 90.38 |
| Typhoon | 96.31 | 95.54 | 95.51 | 92.32 |
| Ro-drip | 83.79 | 86.06 | 86.06 | 79.52 |
| Evaflow | 24.28 | 24.50 | 26.78 | 22.36 |
| Twiom | 95.32 | 95.65 | 95.72 | 94.12 |
| L.S.D. (5%)= | 0.51 | | | |
| (1%)= | 0.69 | | | |

(3*3*5*5)

| Lateral lines | Inlet pressure head (m) | | | | |
|---|---|---|---|---|---|
| | 15 | 12 | 9 | 6 | 3 |
| RAM | 96.40 | 97.03 | 96.85 | 97.50 | 90.38 |
| Typhoon | 96.73 | 96.31 | 95.54 | 95.51 | 92.32 |
| Twiom | 95.19 | 95.32 | 95.65 | 95.72 | 94.12 |
| L.S.D. (5%)= | 0.24 | | | | |
| (1%)= | 0.32 | | | | |

Table (4-12): Effect of interaction between type of lateral line and slope of lateral line on distribution of uniformity (%).

(3*6*2*5)

| Lateral line | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | -2 | -1 | 0 | 1 | 2 |
| RAM | 91.05 | 92.97 | 94.65 | 95.53 | 95.50 |
| Typhoon | 91.87 | 92.45 | 93.12 | 94.96 | 97.16 |
| Ro-drip | 73.16 | 82.09 | 84.11 | 88.87 | 85.71 |
| Ultradrip | 55.81 | 72.38 | 78.49 | 79.60 | 80.85 |
| Evaflow | 11.83 | 20.74 | 27.17 | 30.64 | 32.47 |
| Twiom | 92.13 | 92.81 | 94.92 | 97.33 | 97.42 |
| L.S.D. (5%) = | 1.23 | | | | |
| (1%) = | 1.63 | | | | |

(3*5*4*5)

| | | | | | |
|---|---|---|---|---|---|
| RAM | 93.63 | 95.07 | 95.99 | 96.41 | 96.09 |
| Typhoon | 91.83 | 94.39 | 94.84 | 95.88 | 97.67 |
| Ro-drip | 78.58 | 84.11 | 85.27 | 87.63 | 83.69 |
| Evaflow | 15.49 | 21.70 | 25.98 | 28.84 | 30.40 |
| Twiom | 93.37 | 93.85 | 95.30 | 96.65 | 96.84 |
| L.S.D. (5%)= | 0.54 | | | | |
| (1%)= | 0.71 | | | | |

(3*3*5*5)

| | | | | | |
|---|---|---|---|---|---|
| RAM | 94.24 | 95.56 | 96.07 | 96.38 | 95.90 |
| Typhoon | 92.35 | 94.92 | 95.24 | 95.94 | 97.97 |
| Twiom | 93.50 | 93.95 | 95.31 | 96.50 | 96.74 |
| L.S.D. (5%)= | 0.20 | | | | |
| (1%)= | 0.27 | | | | |

Table (4-13): Effect of interaction between slope of lateral line and inlet pressure head on distribution of uniformity (%).

| Inlet pressure head (m) | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | (3*6*2*5) | | |
| 6 | 77.08 | 79.72 | 80.49 | 83.01 | 83.46 |
| 3 | 61.54 | 71.43 | 77.00 | 79.30 | 79.58 |
| L.S.D. (5%) = | 0.71 | | | | |
| (1%) = | 0.94 | | | | |
| | | | (3*5*4*5) | | |
| 12 | 76.83 | 79.52 | 79.90 | 80.40 | 80.08 |
| 9 | 77.47 | 79.35 | 80.42 | 80.99 | 80.37 |
| 6 | 76.76 | 79.00 | 80.29 | 82.77 | 82.75 |
| 3 | 67.26 | 73.42 | 77.30 | 80.17 | 80.56 |
| L.S.D. (5%)= | 0.48 | | | | |
| (1%)= | 0.64 | | | | |
| | | | (3*3*5*5) | | |
| 15 | 95.04 | 96.31 | 96.17 | 96.12 | 96.88 |
| 12 | 94.06 | 96.26 | 96.66 | 96.84 | 97.29 |
| 9 | 94.35 | 96.00 | 96.39 | 96.52 | 96.80 |
| 6 | 94.89 | 95.09 | 96.08 | 97.16 | 98.01 |
| 3 | 88.48 | 90.39 | 92.39 | 94.73 | 95.38 |
| L.S.D. (5%)= | 0.26 | | | | |
| (1%)= | 0.35 | | | | |

Table (4-14): Effect of interaction between type and slope of lateral line and inlet pressure head on distribution of uniformity (%).

(3*6*2*5)

| Inlet pressure head (m) | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | RAM | | |
| 6 | 97.41 | 97.24 | 97.57 | 97.46 | 97.83 |
| 3 | 84.69 | 88.70 | 91.74 | 93.59 | 93.17 |
| | | | Typhoon | | |
| 6 | 93.73 | 93.98 | 94.56 | 96.67 | 98.60 |
| 3 | 90.02 | 90.92 | 91.69 | 93.26 | 95.72 |
| | | | Ro-drip | | |
| 6 | 78.73 | 86.58 | 85.03 | 91.31 | 88.63 |
| 3 | 67.59 | 77.60 | 83.18 | 86.43 | 82.80 |
| | | | Ultradrip | | |
| 6 | 78.66 | 83.30 | 81.47 | 84.21 | 87.00 |
| 3 | 32.97 | 61.46 | 75.50 | 75.00 | 74.70 |
| | | | Evaflow | | |
| 6 | 20.43 | 23.16 | 28.17 | 31.07 | 31.08 |
| 3 | 3.24 | 18.33 | 26.16 | 30.22 | 33.87 |
| | | | Twiom | | |
| 6 | 93.52 | 94.05 | 96.11 | 97.34 | 97.60 |
| 3 | 90.75 | 91.56 | 93.72 | 97.33 | 97.24 |
| L.S.D. (5%) = | 1.74 | | | | |
| (1%) = | 2.30 | | | | |

Table (4-14): Continue

| Inlet pressure head (m) | Slope of lateral line (%) - 2 | - 1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| (3*5*4*5) | | | | | |
| | | | RAM | | |
| 12 | 95.67 | 97.19 | 97.43 | 97.44 | 97.41 |
| 9 | 96.76 | 97.15 | 97.23 | 97.15 | 95.96 |
| 6 | 97.41 | 97.24 | 97.57 | 97.46 | 97.83 |
| 3 | 84.69 | 88.70 | 91.74 | 93.59 | 93.17 |
| | | | Typhoon | | |
| 12 | 92.13 | 96.75 | 97.10 | 97.25 | 98.33 |
| 9 | 91.46 | 95.90 | 96.01 | 96.33 | 98.02 |
| 6 | 93.73 | 93.98 | 94.56 | 96.67 | 98.60 |
| 3 | 90.02 | 90.92 | 91.69 | 93.26 | 95.72 |
| | | | Ro-drip | | |
| 12 | 83.72 | 85.52 | 85.39 | 84.65 | 79.67 |
| 9 | 84.28 | 86.75 | 87.46 | 88.14 | 83.65 |
| 6 | 78.73 | 86.58 | 85.03 | 91.31 | 88.63 |
| 3 | 67.59 | 77.60 | 83.18 | 86.43 | 82.80 |
| | | | Evaflow | | |
| 12 | 18.25 | 23.30 | 24.12 | 26.86 | 28.85 |
| 9 | 20.03 | 22.00 | 25.46 | 27.21 | 27.80 |
| 6 | 20.43 | 23.16 | 28.17 | 31.07 | 31.08 |
| 3 | 3.24 | 18.33 | 26.16 | 30.22 | 33.87 |
| | | | Twiom | | |
| 12 | 94.39 | 94.84 | 95.43 | 95.82 | 96.12 |
| 9 | 94.83 | 94.96 | 95.93 | 96.10 | 96.41 |
| 6 | 93.52 | 94.05 | 96.11 | 97.34 | 97.60 |
| 3 | 90.75 | 91.56 | 93.72 | 97.33 | 97.24 |
| L.S.D. (5%)= | 1.08 | | | | |
| (1%)= | 1.42 | | | | |
| (3*3*5*5) | | | | | |
| | | | RAM | | |
| 15 | 96.68 | 97.55 | 96.37 | 96.26 | 95.11 |
| 12 | 95.67 | 97.19 | 97.43 | 97.44 | 97.41 |
| 9 | 96.76 | 97.15 | 97.23 | 97.15 | 95.96 |
| 6 | 97.41 | 97.24 | 97.57 | 97.46 | 97.83 |
| 3 | 84.69 | 88.70 | 91.74 | 93.59 | 93.17 |
| | | | Typhoon | | |
| 15 | 94.42 | 97.06 | 96.82 | 96.18 | 99.18 |
| 12 | 92.13 | 96.75 | 97.10 | 97.25 | 98.33 |
| 9 | 91.46 | 95.90 | 96.01 | 96.33 | 98.02 |
| 6 | 93.73 | 93.98 | 94.56 | 96.67 | 98.60 |
| 3 | 90.02 | 90.92 | 91.69 | 93.26 | 95.72 |
| | | | Twiom | | |
| 15 | 94.01 | 94.33 | 95.33 | 95.92 | 96.35 |
| 12 | 94.39 | 94.84 | 95.43 | 95.82 | 96.12 |
| 9 | 94.83 | 94.96 | 95.93 | 96.10 | 96.41 |
| 6 | 93.52 | 94.05 | 96.11 | 97.34 | 97.60 |
| 3 | 90.75 | 91.56 | 93.72 | 97.33 | 97.24 |
| L.S.D. (5%)= | 0.46 | | | | |
| (1%)= | 0.60 | | | | |

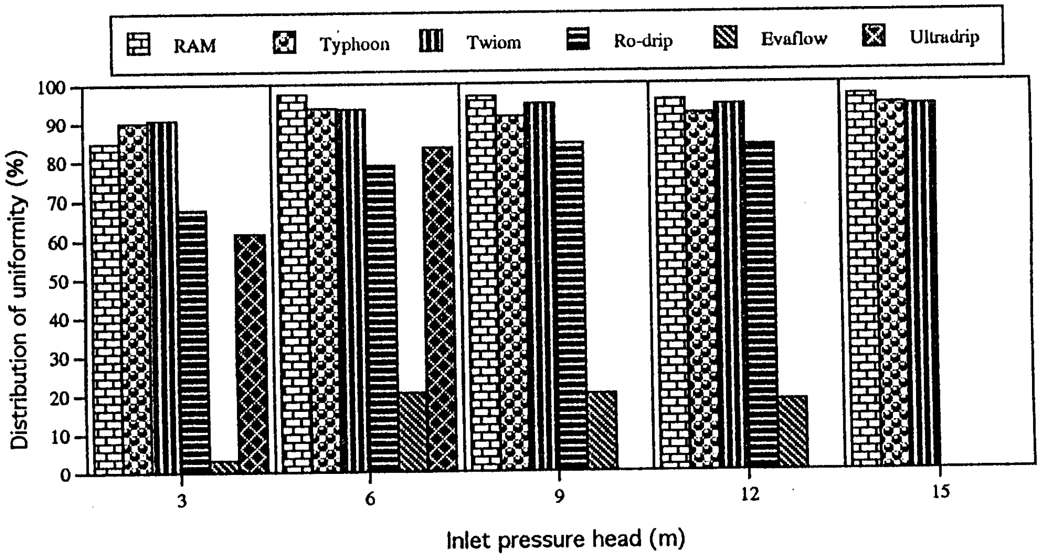


Fig. (4-20):Effect of inlet pressure and type of lateral line on distribution of uniformity at slope -2%.

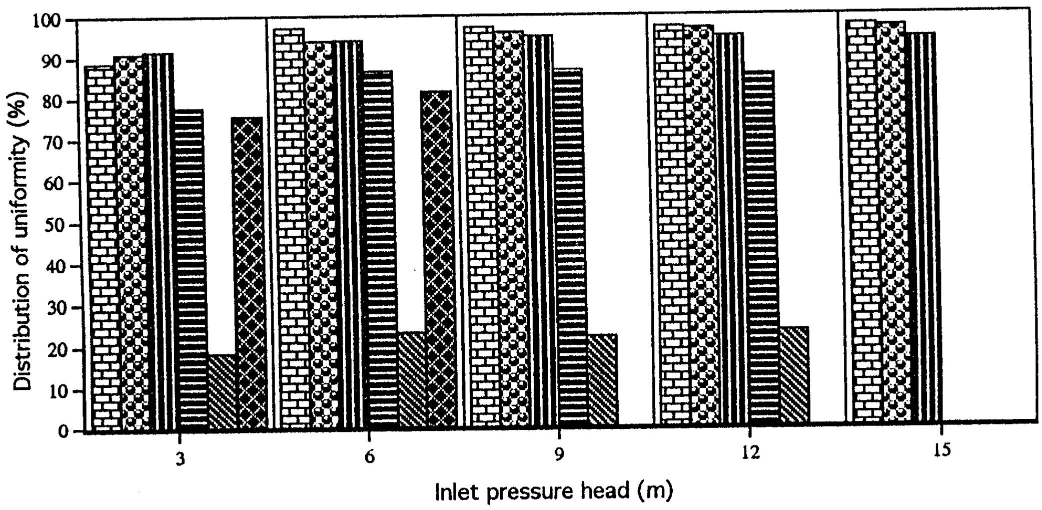


Fig. (4-21): Effect of inlet pressure and type of lateral line on distribution of uniformity at slope -1%.

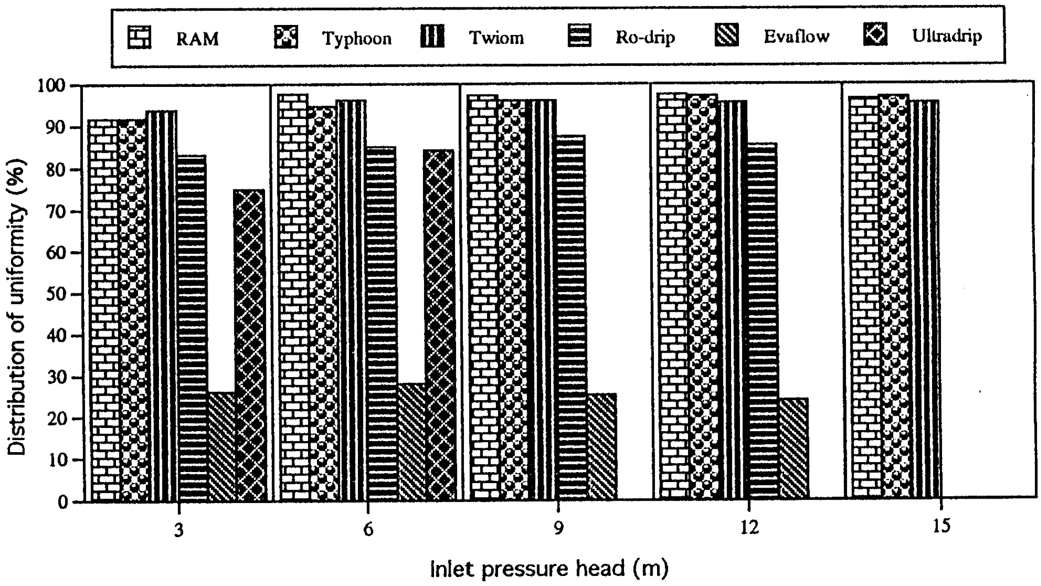


Fig. (4-22): Effect of inlet pressure and type of lateral line on distribution of uniformity at slope 0%.

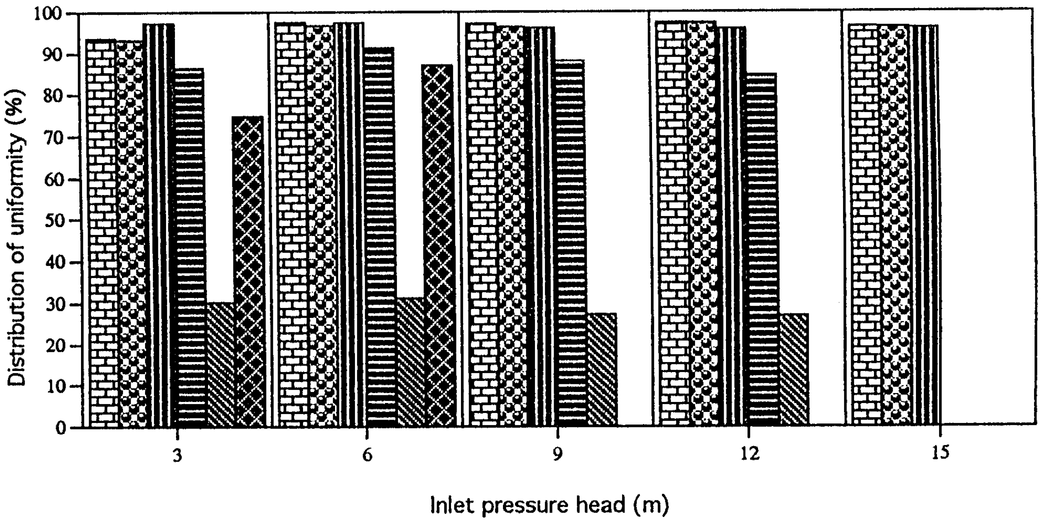


Fig. (4-23): Effect of inlet pressure and type of lateral line on distribution of uniformity at slope 1%.

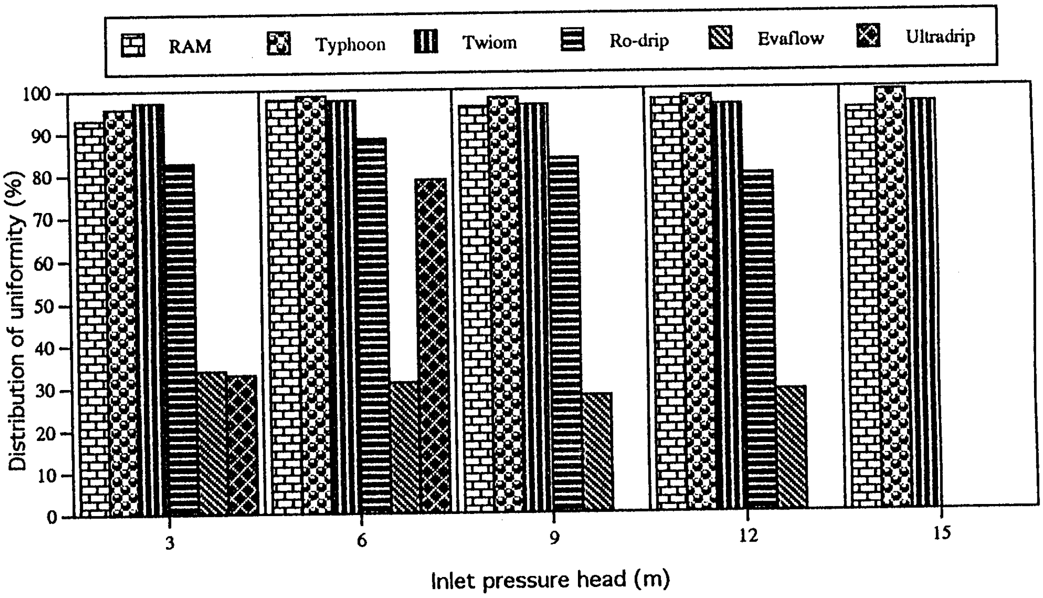


Fig. (4-24): Effect of inlet pressure and type of lateral line on distribution of uniformity at slope 2%.

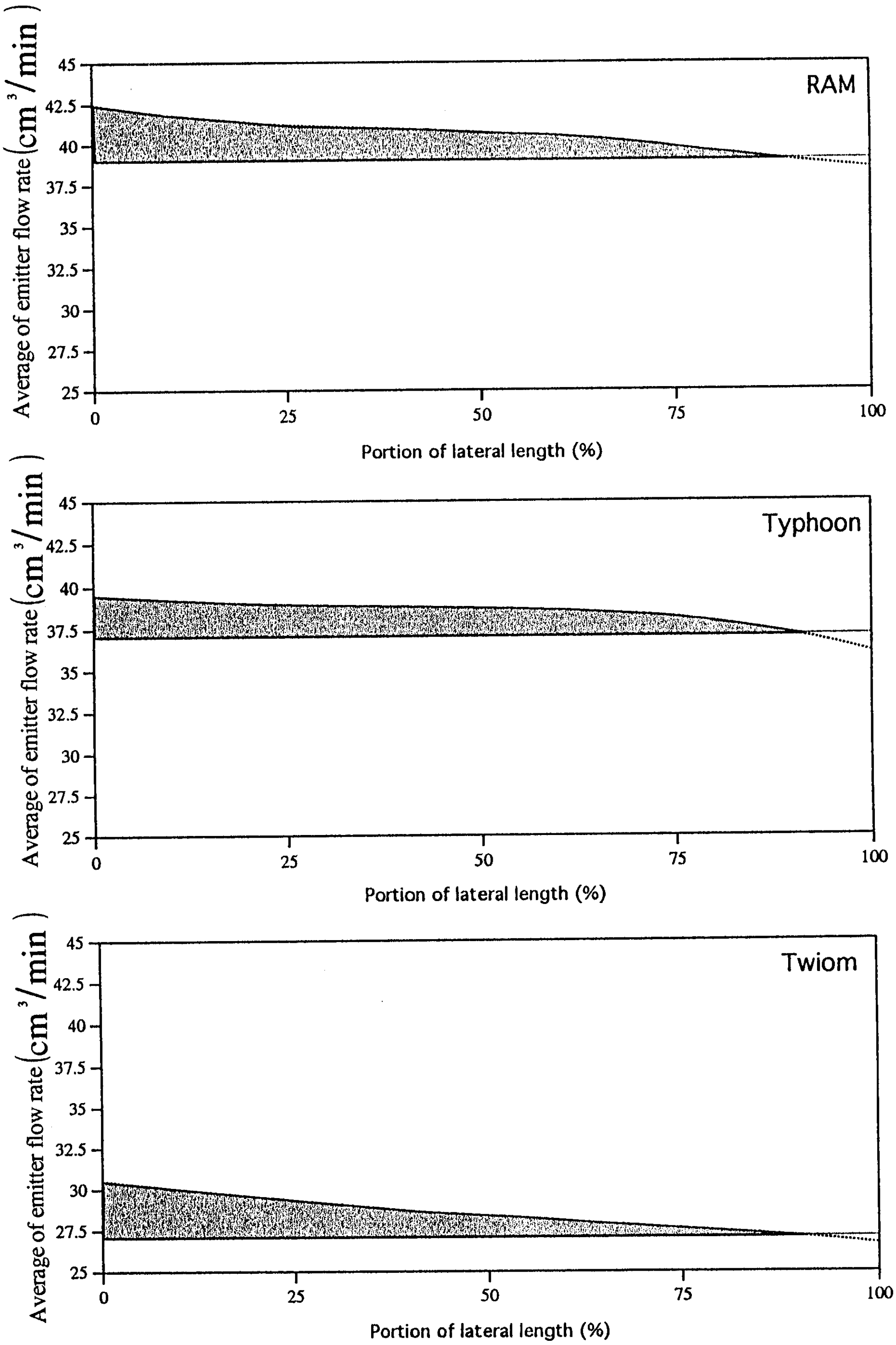


Fig. (4-25): Effect of type of lateral line on excessive water losses at 15 m inlet pressure head.

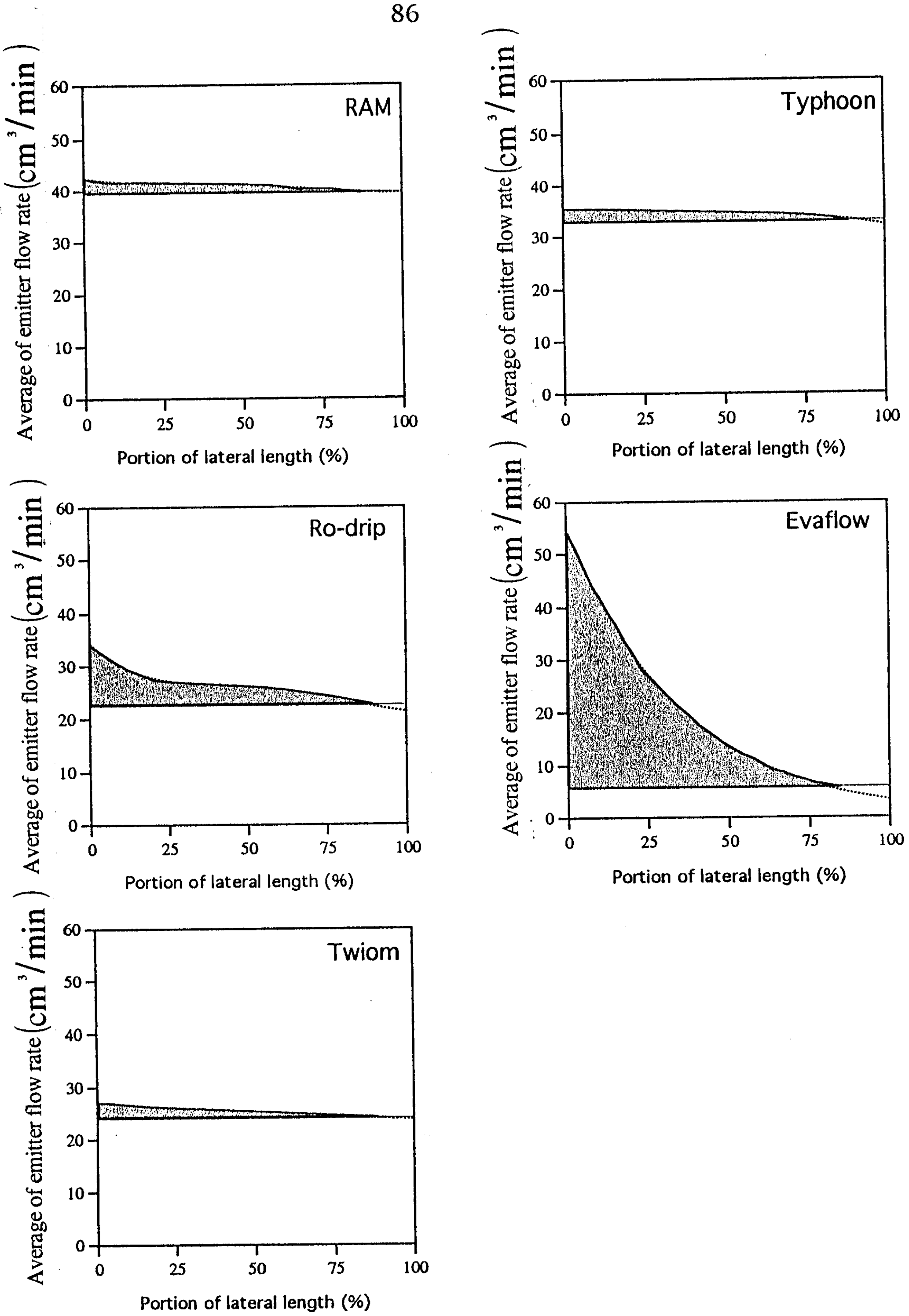


Fig. (4-26): Effect of type of lateral line on excessive water losses at12 m inlet pressure head.

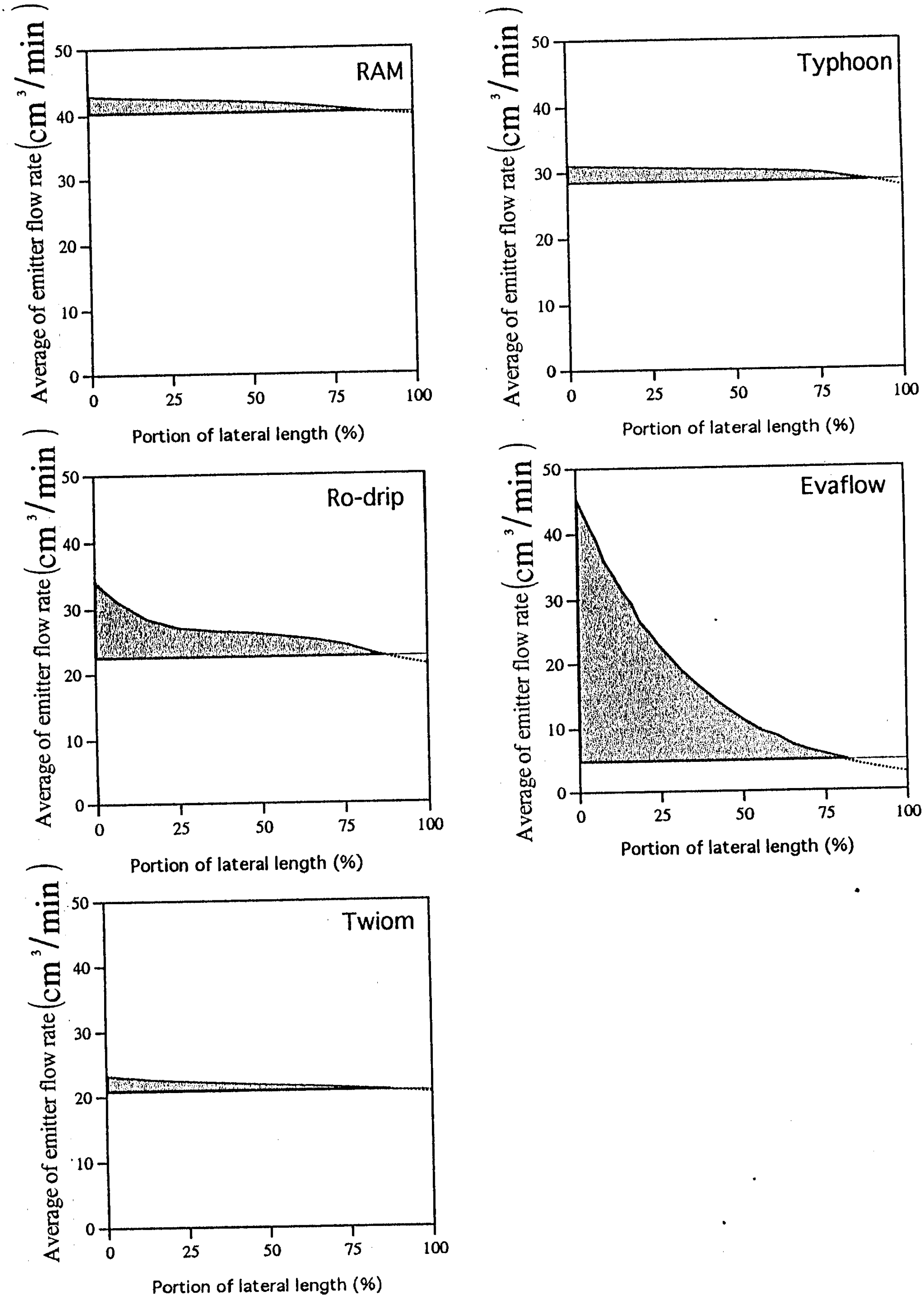


Fig. (4-27):Effect of type of lateral line on excessive water losses at 9 m inlet pressure head.

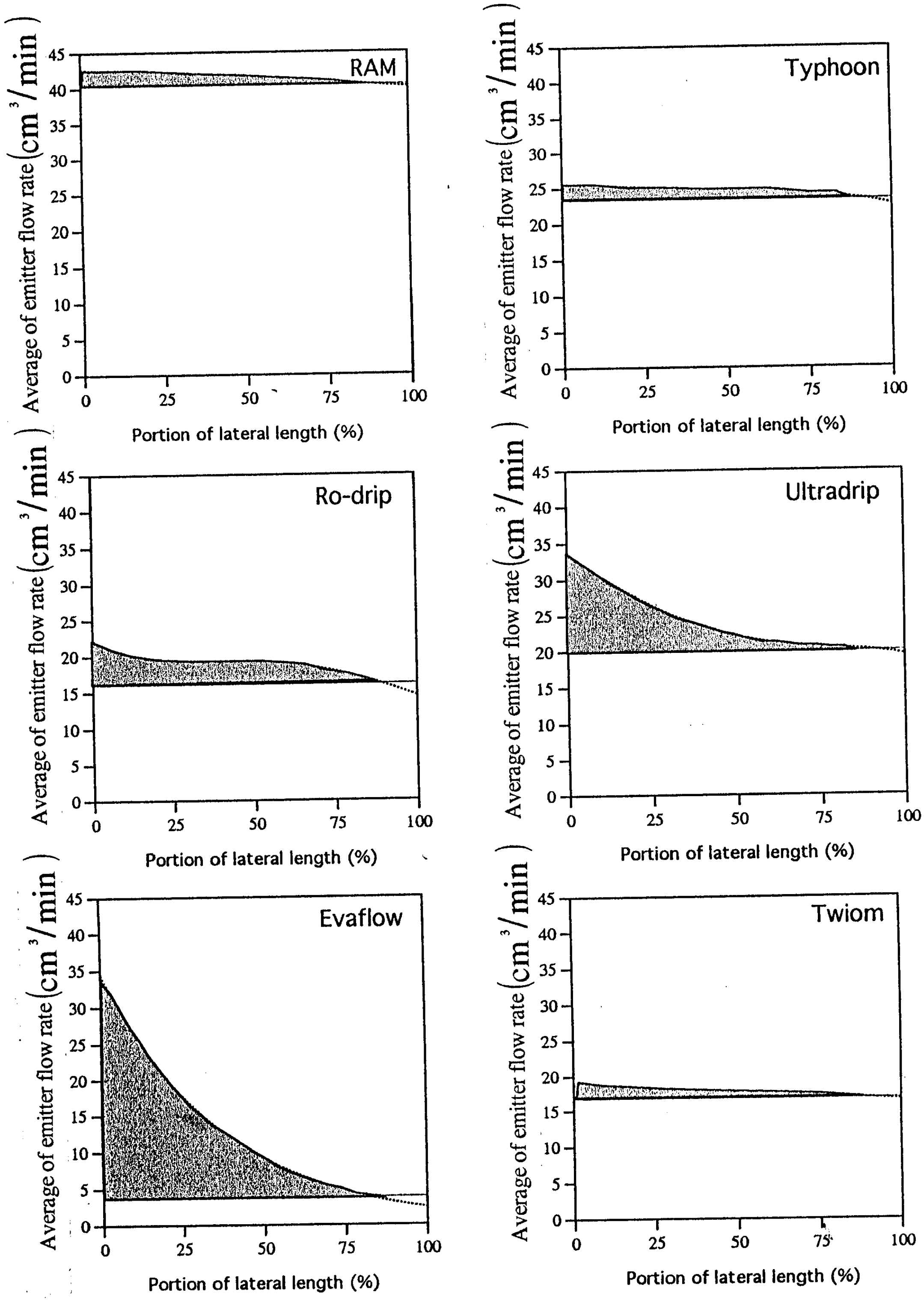


Fig. (4-28): Effect of type of lateral line On excessive water losses at 6 m inlet pressure head.

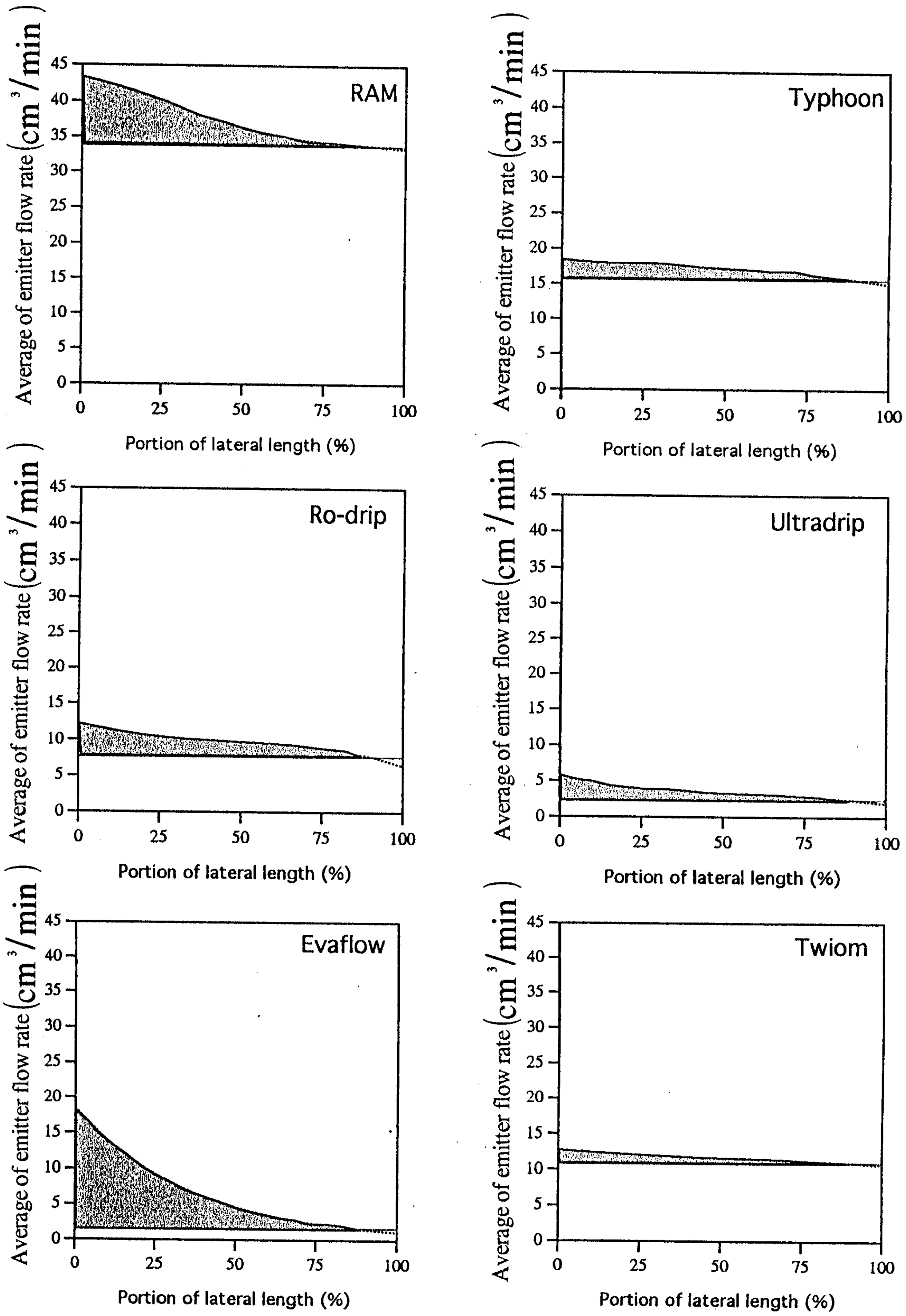


Fig. (4-29): Effect of type of lateral line on excessive water losses at 3 m inlet pressure head.

## 4.8 Head loss ($\Delta H$)

The maximum pressure head difference along the lateral line is called pressure head loss. Usually, it is the difference between the pressure head at the inlet and the end of the lateral line. The pressure head loss is caused by friction loss, emitter connection, reduction of flow rate, and elevation differences (upslope). The ideal design is one which gives the minimum pressure head losses. The experiment results indicated the pressure head losses decreased by increasing slope of lateral lines because there is energy gaih due to the downslope situation. The values of head drop ratio; $R_i$ were plotted versus length ratio of lateral line; $i$ in Figures (4-30 to 4-34) and Figures (5-17 to 5-21 in Appendix) whereas:

$$R_i = \frac{\Delta H_i}{\Delta H}$$

$$i = \frac{l}{L}$$

where:-

$\Delta H_i$ = Head losses at length ratio ($i$) (m)
$\Delta H$ = Total head losses (m)
$l$ = Portion length from lateral line measured from inlet (m)
$L$ = Total length of lateral line (m)

Tables (4-2, 4-15 to 4-18) show the effect of type and slope of lateral line and operating pressure head and their interaction on pressure head losses. The lowest loss in head was 0.85 m for the Ro-drip at 3 m operating head and 2 % slope (Table 4-18). The highest head loss was 11.23 m for the Evaflow at 12 m operating head and -2 % slope because emitter flow rate decreased significantly during the first 1/4 of the lateral line (Table 4-18). The statistical analysis indicated the independent factors and their interaction had a highly significant effect on head losses (Table 5-5 in Appendix).

Regression analysis showed there is a definite relationship between the pressure head losses ($\Delta H$) and both the inlet pressure head and slope of lateral line. The following regression equations for different lateral lines which were calculated from the data in Table (5-6 in Appendix) are:

| | | |
|---|---|---|
| $z = 3.158 - 0.012x - 0.157y$ | R=0.721 | RAM |
| $z = 1.679 + 0.017x - 0.184y$ | R=0.887 | Typhoon |
| $z = 1.474 + 0.182x - 0.128y$ | R=0.987 | Twiom |
| $z = 1.438 + 0.058x - 0.238y$ | R=0.955 | Ro-drip |
| $z = -0.015 + 0.891x - 0.180y$ | R=0.998 | Evaflow |

where :- $z$ =pressure head losses, m
$x$ =inlet pressure head, m
$y$ =slope of lateral line, %

Table (4-15):Effect of interaction between type of lateral line and inlet pressure head on pressure head losses (m).

(3*6*2*5)

| Lateral line | Inlet pressure head (m) | |
|---|---|---|
| | 6 | 3 |
| RAM | 3.26 | 2.88 |
| Typhoon | 1.84 | 1.67 |
| Ro-drip | 1.74 | 1.62 |
| Ultradrip | 2.33 | 1.59 |
| Evaflow | 5.37 | 2.61 |
| Twiom | 2.56 | 2.01 |
| L.S.D. (5%) = | 0.07 | |
| (1%) = | 0.10 | |

(3*5*4*5)

| Lateral line | Inlet pressure head (m) | | | |
|---|---|---|---|---|
| | 12 | 9 | 6 | 3 |
| RAM | 3.09 | 3.24 | 3.26 | 2.88 |
| Typhoon | 1.77 | 1.92 | 1.84 | 1.67 |
| Ro-drip | 2.11 | 2.01 | 1.74 | 1.62 |
| Evaflow | 10.63 | 8.04 | 5.37 | 2.61 |
| Twiom | 3.65 | 3.13 | 2.56 | 2.01 |
| L.S.D. (5%)= | 0.10 | | | |
| (1%)= | 0.13 | | | |

(3*3*5*5)

| Lateral lines | Inlet pressure head (m) | | | | |
|---|---|---|---|---|---|
| | 15 | 12 | 9 | 6 | 3 |
| RAM | 2.78 | 3.09 | 3.24 | 3.26 | 2.88 |
| Typhoon | 1.96 | 1.77 | 1.92 | 1.84 | 1.67 |
| Twiom | 4.19 | 3.65 | 3.13 | 2.56 | 2.01 |
| L.S.D. (5%)= | 0.12 | | | | |
| (1%)= | 0.16 | | | | |

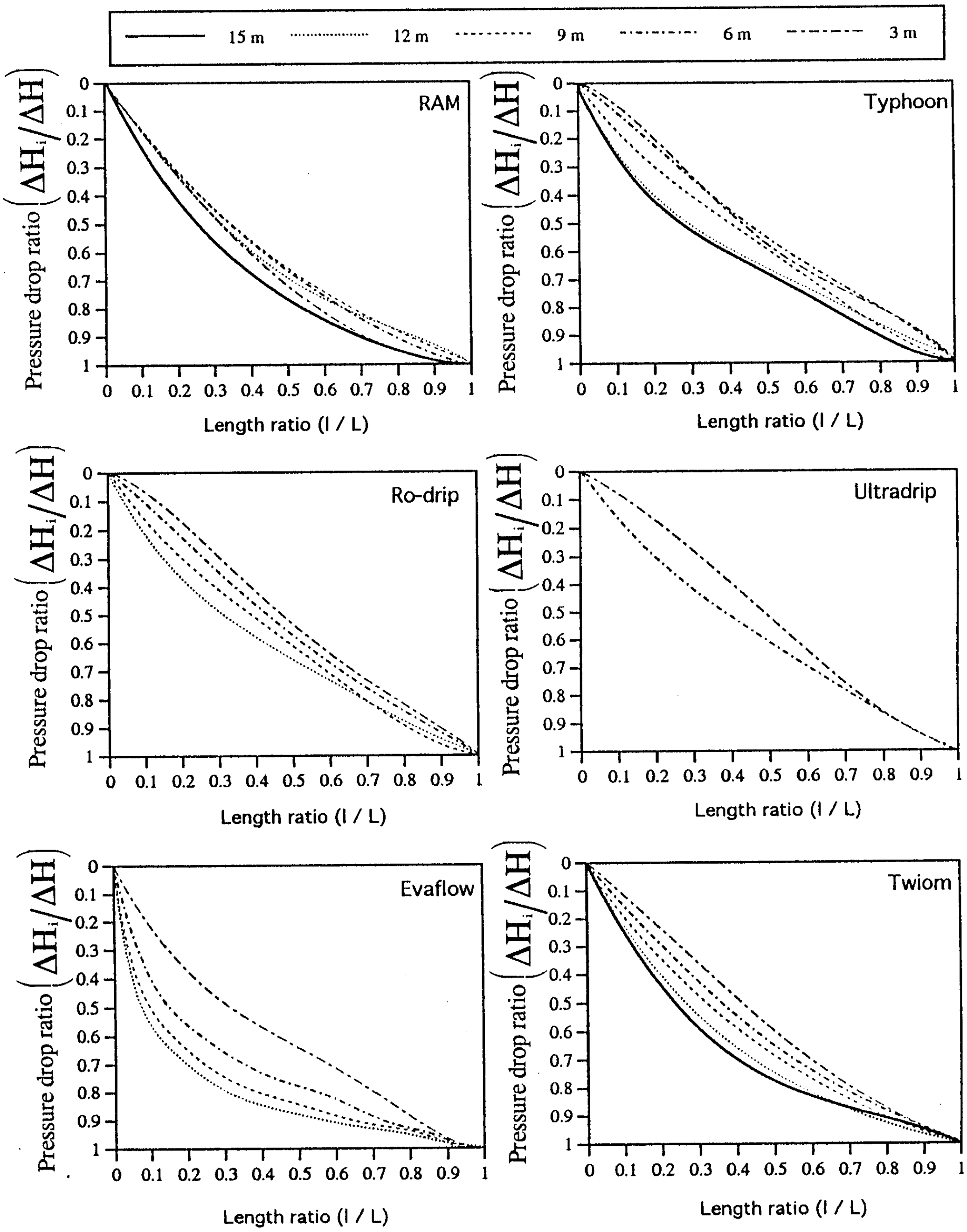


Fig. (4-30): Effect of inlet pressure head and type of lateral line on pressure drop ratio at -2 % slope.

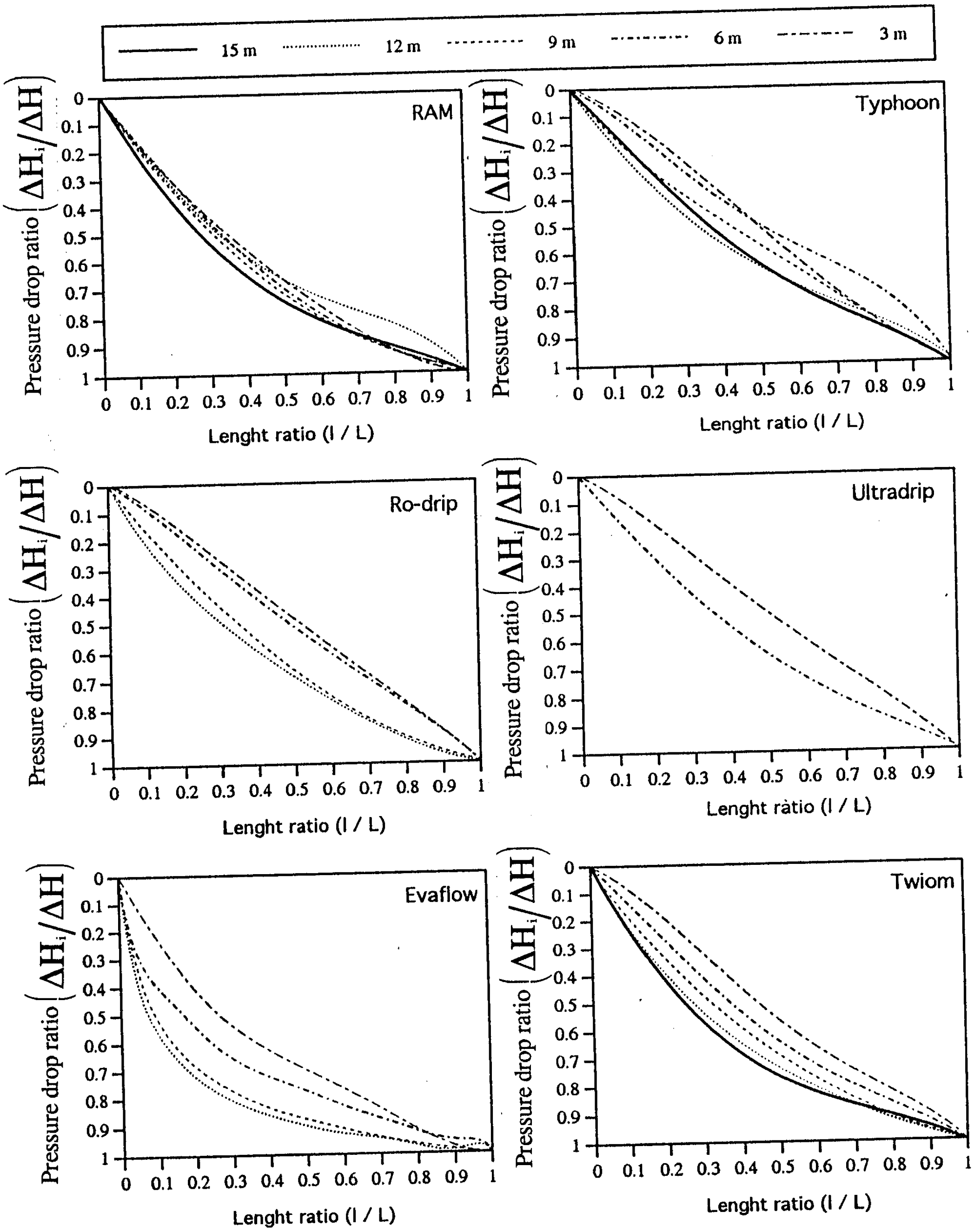


Fig. (4-31): Effect of inlet pressure head and type of lateral line on pressure drop ratio at -1 % slope.

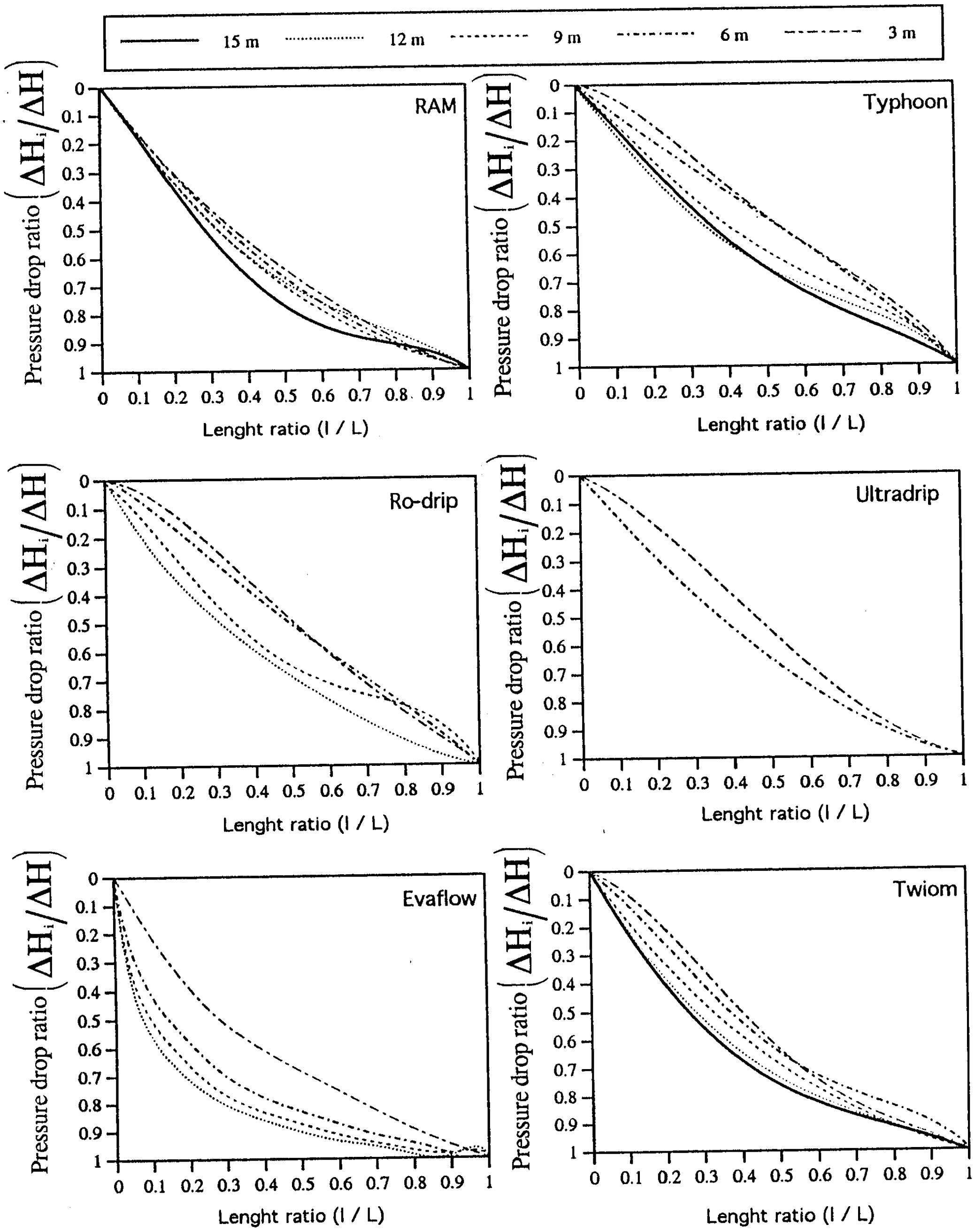


Fig. (4-32): Effect of inlet pressure head and type of lateral line on pressure drop ratio at 0 % slope.

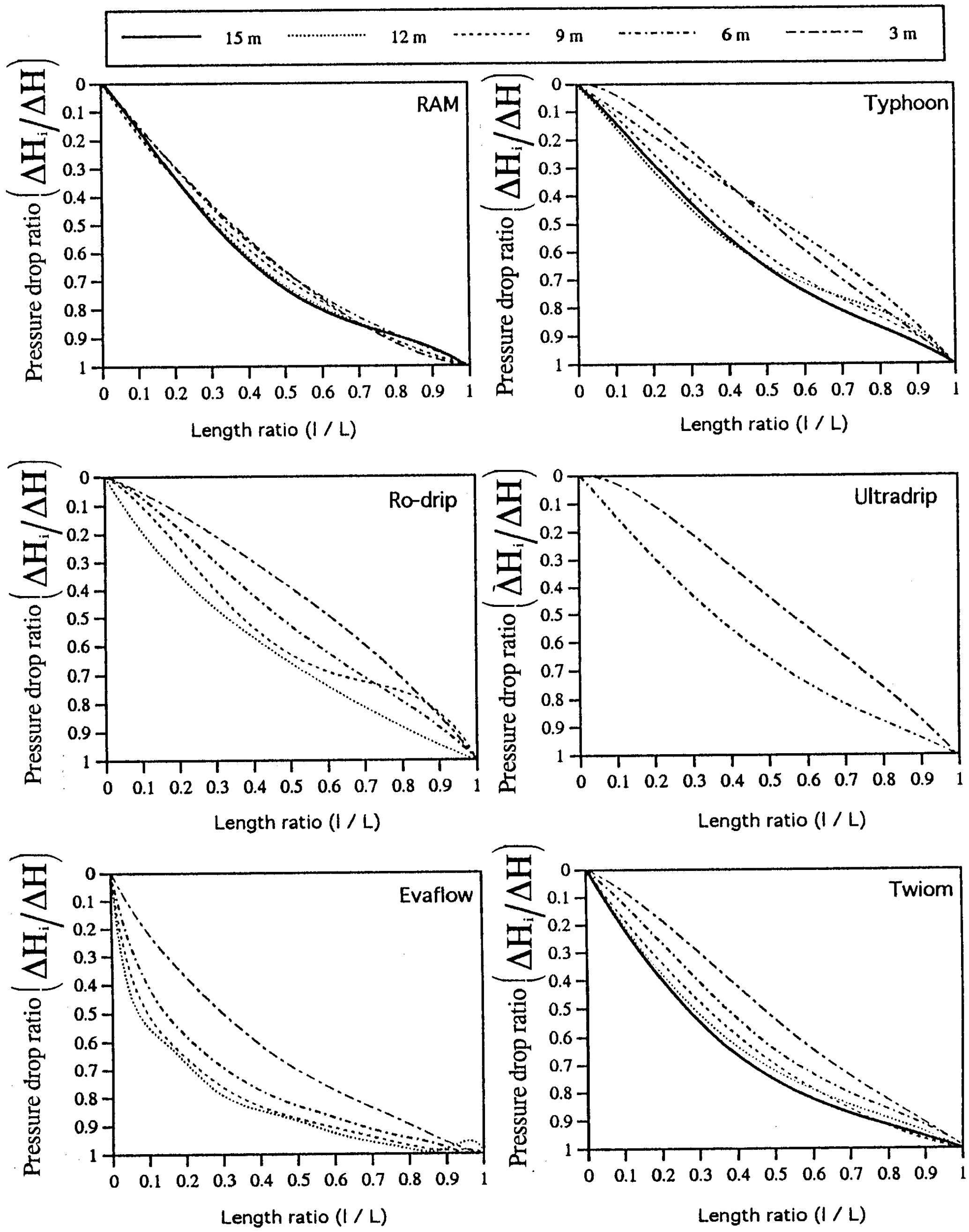


Fig. (4-33): Effect of inlet pressure head and type of lateral line on pressure drop ratio at 1 % slope.

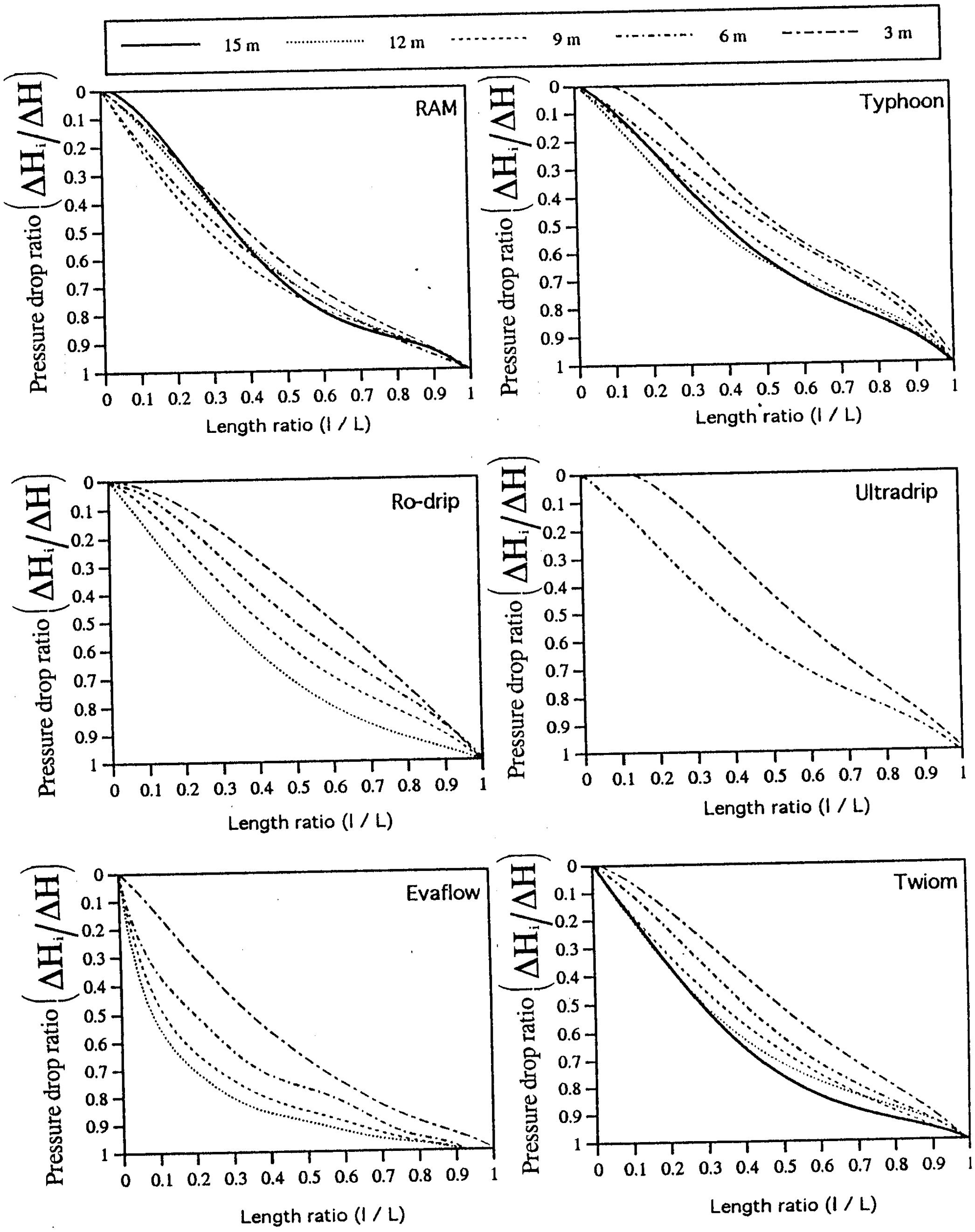


Fig. (4-34): Effect of inlet pressure head and type of lateral line on pressure drop ratio at 2 % slope.

Table (4-16):Effect of interaction between type and slope of lateral line on pressure head losses (m).

| Lateral line | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| (3*6*2*5) | | | | | |
| RAM | 3.44 | 3.19 | 3.05 | 2.91 | 2.75 |
| Typhoon | 2.19 | 2.09 | 1.79 | 1.56 | 1.15 |
| Ro-drip | 2.09 | 2.04 | 1.75 | 1.53 | 0.99 |
| Ultradrip | 2.57 | 2.31 | 1.96 | 1.7 | 1.25 |
| Evaflow | 4.34 | 4.13 | 3.88 | 3.82 | 3.79 |
| Twiom | 2.7 | 2.6 | 2.21 | 2.04 | 1.89 |
| L.S.D. (5%) = | 0.08 | | | | |
| (1%) = | 0.11 | | | | |
| (3*5*4*5) | | | | | |
| RAM | 3.52 | 3.23 | 3.08 | 2.93 | 2.82 |
| Typhoon | 2.14 | 2.02 | 1.82 | 1.64 | 1.38 |
| Ro-drip | 2.28 | 2.13 | 1.92 | 1.74 | 1.29 |
| Evaflow | 7.08 | 6.79 | 6.6 | 6.54 | 6.31 |
| Twiom | 3.13 | 3.02 | 2.8 | 2.67 | 2.57 |
| L.S.D. (5%)= | 0.07 | | | | |
| (1%)= | 0.10 | | | | |
| (3*3*5*5) | | | | | |
| RAM | 3.41 | 3.17 | 3.01 | 2.88 | 2.77 |
| Typhoon | 2.19 | 2.03 | 1.83 | 1.67 | 1.45 |
| Twiom | 3.36 | 3.27 | 3.08 | 2.96 | 2.87 |
| L.S.D. (5%)= | 0.10 | | | | |
| (1%)= | 0.13 | | | | |

Table (4-17): Effect of interaction between inlet pressure head and slope of lateral line on pressure losses (m).

| Inlet pressure head (m) | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| (3*6*2*5) | | | | | |
| 6 | 3.28 | 3.08 | 2.84 | 2.68 | 2.37 |
| 3 | 2.49 | 2.37 | 2.05 | 1.84 | 1.57 |
| L.S.D. (5%) = | 0.05 | | | | |
| (1%) = | 0.06 | | | | |
| (3*5*4*5) | | | | | |
| 12 | 4.55 | 4.39 | 4.26 | 4.16 | 3.89 |
| 9 | 4.07 | 3.75 | 3.63 | 3.51 | 3.38 |
| 6 | 3.35 | 3.19 | 2.92 | 2.79 | 2.52 |
| 3 | 2.55 | 2.42 | 2.15 | 1.96 | 1.71 |
| L.S.D. (5%)= | 0.06 | | | | |
| (1%)= | 0.09 | | | | |
| (3*3*5*5) | | | | | |
| 15 | 3.21 | 3.07 | 2.94 | 2.88 | 2.78 |
| 12 | 3.01 | 2.95 | 2.83 | 2.73 | 2.66 |
| 9 | 3.15 | 2.84 | 2.73 | 2.58 | 2.51 |
| 6 | 2.99 | 2.77 | 2.53 | 2.37 | 2.11 |
| 3 | 2.56 | 2.48 | 2.17 | 1.96 | 1.75 |
| L.S.D. (5%)= | 0.12 | | | | |
| (1%)= | 0.16 | | | | |

Table (4-18): Effect of interaction between type and slope of lateral line and inlet pressure head on pressure head losses (m).

(3*6*2**5)

| Inlet pressure head (m) | Slope of lateral line (%) -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | RAM | | |
| 6 | 3.88 | 3.39 | 3.12 | 3.03 | 2.84 |
| 3 | 3 | 2.99 | 2.98 | 2.78 | 2.65 |
| | | | Typhoon | | |
| 6 | 2.19 | 2.15 | 1.89 | 1.72 | 1.27 |
| 3 | 2.19 | 2.03 | 1.69 | 1.4 | 1.03 |
| | | | Ro-drip | | |
| 6 | 2.08 | 2.01 | 1.83 | 1.63 | 1.13 |
| 3 | 2.11 | 2.06 | 1.68 | 1.43 | 0.85 |
| | | | Ultradrip | | |
| 6 | 2.94 | 2.55 | 2.4 | 2.13 | 1.63 |
| 3 | 2.19 | 2.08 | 1.53 | 1.27 | 0.87 |
| | | | Evaflow | | |
| 6 | 5.7 | 5.65 | 5.19 | 5.18 | 5.14 |
| 3 | 2.97 | 2.61 | 2.57 | 2.47 | 2.45 |
| | | | Twiom | | |
| 6 | 2.9 | 2.77 | 2.58 | 2.36 | 2.21 |
| 3 | 2.5 | 2.43 | 1.84 | 1.71 | 1.57 |
| L.S.D. (5%) = | 0.11 | | | | |
| (1%) = | 0.15 | | | | |

(3*5*4*5)

| Inlet pressure head (m) | -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | RAM | | |
| 12 | 3.4 | 3.31 | 3.06 | 2.86 | 2.8 |
| 9 | 3.82 | 3.22 | 3.15 | 3.05 | 2.98 |
| 6 | 3.88 | 3.39 | 3.12 | 3.03 | 2.84 |
| 3 | 3 | 2.99 | 2.98 | 2.78 | 2.65 |
| | | | Typhoon | | |
| 12 | 1.92 | 1.85 | 1.79 | 1.71 | 1.6 |
| 9 | 2.25 | 2.07 | 1.9 | 1.72 | 1.63 |
| 6 | 2.19 | 2.15 | 1.89 | 1.72 | 1.27 |
| 3 | 2.19 | 2.03 | 1.69 | 1.4 | 1.03 |
| | | | Ro-drip | | |
| 12 | 2.47 | 2.26 | 2.14 | 2.01 | 1.68 |
| 9 | 2.48 | 2.17 | 2.03 | 1.89 | 1.5 |
| 6 | 2.08 | 2.01 | 1.83 | 1.63 | 1.13 |
| 3 | 2.11 | 2.06 | 1.68 | 1.43 | 0.85 |
| | | | Evaflow | | |
| 12 | 11.23 | 10.87 | 10.67 | 10.6 | 9.78 |
| 9 | 8.43 | 8.05 | 7.96 | 7.9 | 7.87 |
| 6 | 5.7 | 5.65 | 5.19 | 5.18 | 5.14 |
| 3 | 2.97 | 2.61 | 2.57 | 2.47 | 2.45 |
| | | | Twiom | | |
| 12 | 3.72 | 3.67 | 3.64 | 3.62 | 3.6 |
| 9 | 3.38 | 3.23 | 3.13 | 2.98 | 2.92 |
| 6 | 2.9 | 2.77 | 2.58 | 2.36 | 2.21 |
| 3 | 2.5 | 2.43 | 1.84 | 1.71 | 1.57 |
| L.S.D. (5%)= | 0.14 | | | | |
| (1%)= | 0.19 | | | | |

Table (4-18):Continue

(3*3*5*5)

| Inlet pressure head (m) | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| | | | RAM | | |
| 15 | 2.96 | 2.91 | 2.76 | 2.69 | 2.58 |
| 12 | 3.4 | 3.31 | 3.06 | 2.86 | 2.8 |
| 9 | 3.82 | 3.22 | 3.15 | 3.05 | 2.98 |
| 6 | 3.88 | 3.39 | 3.12 | 3.03 | 2.84 |
| 3 | 3 | 2.99 | 2.98 | 2.78 | 2.65 |
| | | | Typhoon | | |
| 15 | 2.37 | 2.06 | 1.86 | 1.79 | 1.71 |
| 12 | 1.92 | 1.85 | 1.79 | 1.71 | 1.6 |
| 9 | 2.25 | 2.07 | 1.9 | 1.72 | 1.63 |
| 6 | 2.19 | 2.15 | 1.89 | 1.72 | 1.27 |
| 3 | 2.19 | 2.03 | 1.69 | 1.4 | 1.03 |
| | | | Twiom | | |
| 15 | 4.31 | 4.24 | 4.2 | 4.15 | 4.06 |
| 12 | 3.72 | 3.67 | 3.64 | 3.62 | 3.6 |
| 9 | 3.38 | 3.23 | 3.13 | 2.98 | 2.92 |
| 6 | 2.9 | 2.77 | 2.58 | 2.36 | 2.21 |
| 3 | 2.5 | 2.43 | 1.84 | 1.71 | 1.57 |

L.S.D. (5%)= 0.21
(1%)= 0.28

## 4.9 Coefficient of uniformity

Ideally, the application of water throughout a trickle system should be absolutely uniform. For uniform spaced emitters, this would require that each emitter have the same rate of discharge even though pressure differences are unavailable. The present study included different types and slopes of lateral line and inlet pressure heads to achieve better uniformity of the system.

Tables (4-2, 4-19 to 4-22) and Figures (4-35 to 4-40) show the values of coefficient of uniformity (Eq. 3-6) for the previous independent factors and their interactions. The statistical analysis indicated the independent variables had a highly significant effect on coefficient uniformity (Table 5-8 in Appendix). The Typhoon was the best lateral line while $UC$ value for it was 99.43 % at 15 m of operating head and 2 % slope (Table 4-22). The lowest coefficient of uniformity was 0 % with the Evaflow lateral line at 12 m of operating head and -2 % slope (Table 4-22). From the obtained results the lateral lines could be arranged as follows: Twiom, Typhoon, RAM, Ro-drip, Ultradrip, and Evaflow whereas $UC$ values for them were 96.11, 96.00, 95.12, 88.78, 76.48, and 23.35 % respectively (Table 4-2).

Regression analysis showed there is a definite relationship between the coefficient of uniformity and both of the inlet pressure head and slope of lateral line. The following regression equations for different lateral lines which were calculated from the data in Table (5-7 in Appendix) are.

$$z = 62.462 + 16.108x - 2.598x^2 + 0.178x^3 - 0.004x^4 + 0.431y \quad r=0.909 \text{ (RAM)}$$
$$z = 90.778 + 1.946x - 0.182x^2 + 0.006x^3 + 0.070y - 0.095y^2 + 0.222y^3 \quad r=0.965 \text{ (Typhoon)}$$
$$z = 92.602 + 1.352x - 0.132x^2 + 0.004x^3 + 1.085y - 0.042y^2 - 0.103y^3 \quad r=0.883 \text{ (Twiom)}$$
$$z = 71.774 + 7.916x - 0.888x^2 + 0.028x^3 + 1.214y - 1.019y^2 + 0.083y^3 \quad r=0.906 \text{ (Ro-drip)}$$
$$z = 59.246 - 10.979x + 0.750x^2 - 0.018x^3 + 4.209y - 0.575y^2 - 0.232y^3 \quad r=0.977 \text{ (Evaflow)}$$

where :- $z$=coefficient of uniformity, %
$x$=inlet pressure head, m
$y$=slope of lateral line, %

Table (4-19):Effect of interaction between type of lateral line and inlet pressure head on coefficient of uniformity (%).

(3*6*2*5)

| Lateral line | Inlet pressure head (m) | |
|---|---|---|
| | 6 | 3 |
| RAM | 98.38 | 91.86 |
| Typhoon | 97.10 | 94.90 |
| Ro-drip | 91.31 | 86.25 |
| Ultradrip | 83.72 | 69.25 |
| Evaflow | 15.29 | 31.42 |
| Twiom | 96.76 | 95.47 |
| L.S.D. (5%) = | 1.20 | |
| (1%) = | 1.68 | |

(3*5*4*5)

| Lateral line | Inlet pressure head (m) | | | |
|---|---|---|---|---|
| | 12 | 9 | 6 | 3 |
| RAM | 98.11 | 97.99 | 98.38 | 91.86 |
| Typhoon | 97.72 | 97.28 | 97.10 | 94.90 |
| Ro-drip | 85.12 | 89.43 | 91.31 | 86.25 |
| Evaflow | 2.29 | 6.75 | 15.29 | 31.42 |
| Twiom | 96.57 | 96.73 | 96.76 | 95.47 |
| L.S.D. (5%)= | 0.49 | | | |
| (1%)= | 0.66 | | | |

(3*3*5*5)

| Lateral lines | Inlet pressure head (m) | | | | |
|---|---|---|---|---|---|
| | 15 | 12 | 9 | 6 | 3 |
| RAM | 97.54 | 98.11 | 97.99 | 98.38 | 91.86 |
| Typhoon | 97.98 | 97.72 | 97.28 | 97.10 | 94.90 |
| Twiom | 96.39 | 96.57 | 96.73 | 96.76 | 95.47 |
| L.S.D. (5%)= | 0.17 | | | | |
| (1%)= | 0.22 | | | | |

Table (4-20):Effect of interaction between type and slope of lateral line on coefficient of uniformity (%).

| Lateral line | Slope of lateral line (%) | | | | |
|---|---|---|---|---|---|
| | - 2 | - 1 | 0 | 1 | 2 |
| (3*6*2*5) | | | | | |
| RAM | 92.79 | 94.15 | 95.46 | 96.43 | 96.76 |
| Typhoon | 93.80 | 95.41 | 95.87 | 96.72 | 98.20 |
| Ro-drip | 81.69 | 88.99 | 89.48 | 92.87 | 90.88 |
| Ultradrip | 61.09 | 72.65 | 79.81 | 83.63 | 85.24 |
| Evaflow | 12.08 | 18.09 | 27.23 | 29.64 | 29.72 |
| Twiom | 94.19 | 94.38 | 96.04 | 97.76 | 98.20 |
| L.S.D. (5%) = | 1.09 | | | | |
| (1%) = | 1.44 | | | | |
| (3*5*4*5) | | | | | |
| RAM | 95.15 | 96.18 | 96.88 | 97.35 | 97.38 |
| Typhoon | 94.44 | 96.57 | 96.85 | 97.39 | 98.52 |
| Ro-drip | 82.62 | 88.87 | 88.38 | 91.46 | 88.80 |
| Evaflow | 5.68 | 10.60 | 15.33 | 18.56 | 19.51 |
| Twiom | 94.96 | 95.29 | 96.48 | 97.43 | 97.75 |
| L.S.D. (5%)= | 0.44 | | | | |
| (1%)= | 0.58 | | | | |
| (3*3*5*5) | | | | | |
| RAM | 95.58 | 96.57 | 97.01 | 97.41 | 97.31 |
| Typhoon | 94.88 | 96.87 | 97.08 | 97.45 | 98.70 |
| Twiom | 94.96 | 95.39 | 96.54 | 97.36 | 97.66 |
| L.S.D. (5%)= | 0.14 | | | | |
| (1%)= | 0.18 | | | | |

Table (4-21): Effect of interaction between slope of lateral line and inlet pressure head on coefficient of uniformity (%).

| Inlet pressure head (m) | Slope of lateral line (%) -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | (3*6*2*5) | | |
| 6 | 76.87 | 79.43 | 80.47 | 82.59 | 82.77 |
| 3 | 68.34 | 75.13 | 80.83 | 83.09 | 83.57 |
| L.S.D. (5%) = | 0.63 | | | | |
| (1%) = | 0.83 | | | | |
| | | | (3*5*4*5) | | |
| 12 | 73.16 | 75.94 | 75.68 | 77.32 | 77.71 |
| 9 | 75.29 | 77.66 | 77.82 | 79.06 | 78.35 |
| 6 | 76.10 | 78.67 | 80.43 | 82.01 | 81.62 |
| 3 | 73.73 | 77.73 | 81.21 | 83.35 | 83.88 |
| L.S.D. (5%)= | 0.39 | | | | |
| (1%)= | 0.52 | | | | |
| | | | (3*3*5*5) | | |
| 15 | 96.31 | 97.35 | 97.45 | 97.48 | 97.93 |
| 12 | 96.07 | 97.51 | 97.72 | 97.86 | 98.19 |
| 9 | 96.14 | 97.24 | 97.64 | 97.77 | 97.90 |
| 6 | 96.38 | 96.72 | 97.29 | 98.07 | 98.60 |
| 3 | 90.81 | 92.58 | 94.29 | 95.87 | 96.84 |
| L.S.D. (5%)= | 0.18 | | | | |
| (1%)= | 0.24 | | | | |

Table (4-22): Effect of interaction between type and slope of lateral line and inlet pressure head on coefficient of uniformity (%)

| Inlet pressure head (m) | Slope of lateral line (%) -2 | -1 | 0 | 1 | 2 |
|---|---|---|---|---|---|
| | | | (3*6*2*5) | | |
| | | | RAM | | |
| 6 | 98.34 | 98.22 | 98.35 | 98.30 | 98.67 |
| 3 | 87.24 | 90.09 | 92.57 | 94.56 | 94.84 |
| | | | Typhoon | | |
| 6 | 95.48 | 96.39 | 96.73 | 97.93 | 98.98 |
| 3 | 92.13 | 94.43 | 95.02 | 95.51 | 97.43 |
| | | | Ro-drip | | |
| 6 | 85.70 | 91.92 | 90.97 | 94.78 | 93.18 |
| 3 | 77.67 | 86.06 | 87.99 | 90.96 | 88.57 |
| | | | Ultradrip | | |
| 6 | 80.73 | 83.21 | 80.68 | 85.50 | 88.49 |
| 3 | 41.44 | 62.10 | 78.95 | 81.76 | 81.98 |
| | | | Evaflow | | |
| 6 | 5.64 | 11.29 | 19.28 | 21.08 | 19.13 |
| 3 | 18.52 | 24.88 | 35.17 | 38.20 | 40.32 |
| | | | Twiom | | |
| 6 | 95.32 | 95.55 | 96.80 | 97.98 | 98.14 |
| 3 | 93.06 | 93.21 | 95.28 | 97.53 | 98.25 |
| L.S.D. (5%) = | 1.53 | | | | |
| (1%) = | 2.38 | | | | |

Table (4-22): Continue

| | | | (3*5*4*5) | | |
|---|---|---|---|---|---|
| | | | RAM | | |
| 12 | 97.15 | 98.31 | 98.36 | 98.34 | 98.41 |
| 9 | 97.87 | 98.10 | 98.24 | 98.19 | 97.57 |
| 6 | 98.34 | 98.22 | 98.35 | 98.30 | 98.67 |
| 3 | 87.24 | 90.09 | 92.57 | 94.56 | 94.84 |
| | | | Typhoon | | |
| 12 | 95.26 | 97.95 | 98.12 | 98.35 | 98.94 |
| 9 | 94.88 | 97.49 | 97.52 | 97.78 | 98.74 |
| 6 | 95.48 | 96.39 | 96.73 | 97.93 | 98.98 |
| 3 | 92.13 | 94.43 | 95.02 | 95.51 | 97.43 |
| | | | Ro-drip | | |
| 12 | 80.41 | 86.73 | 84.54 | 87.86 | 86.09 |
| 9 | 86.69 | 90.77 | 90.04 | 92.26 | 87.38 |
| 6 | 85.70 | 91.92 | 90.97 | 94.78 | 93.18 |
| 3 | 77.67 | 86.06 | 87.99 | 90.96 | 88.57 |
| | | | Evaflow | | |
| 12 | 0.00 | 0.43 | 0.71 | 5.20 | 7.92 |
| 9 | 1.36 | 5.80 | 6.17 | 9.74 | 10.66 |
| 6 | 5.64 | 11.29 | 19.28 | 21.08 | 19.13 |
| 3 | 18.52 | 24.88 | 35.17 | 38.20 | 40.32 |
| | | | Twiom | | |
| 12 | 95.80 | 96.27 | 96.67 | 96.88 | 97.21 |
| 9 | 95.66 | 96.12 | 97.15 | 97.34 | 97.39 |
| 6 | 95.32 | 95.55 | 96.80 | 97.98 | 98.14 |
| 3 | 93.06 | 93.21 | 95.28 | 97.53 | 98.25 |
| L.S.D. (5%)= | 0.88 | | | | |
| (1%)= | 1.15 | | | | |

| | | | (3*3*5*5) | | |
|---|---|---|---|---|---|
| Inlet pressure head (m) | Slope of lateral line (%) | | | | |
| | - 2 | - 1 | 0 | 1 | 2 |
| | | | RAM | | |
| 15 | 97.30 | 98.15 | 97.54 | 97.67 | 97.07 |
| 12 | 97.15 | 98.31 | 98.36 | 98.34 | 98.41 |
| 9 | 97.87 | 98.10 | 98.24 | 98.19 | 97.57 |
| 6 | 98.34 | 98.22 | 98.35 | 98.30 | 98.67 |
| 3 | 87.24 | 90.09 | 92.57 | 94.56 | 94.84 |
| | | | Typhoon | | |
| 15 | 96.64 | 98.10 | 98.03 | 97.71 | 99.43 |
| 12 | 95.26 | 97.95 | 98.12 | 98.35 | 98.94 |
| 9 | 94.88 | 97.49 | 97.52 | 97.78 | 98.74 |
| 6 | 95.48 | 96.39 | 96.73 | 97.93 | 98.98 |
| 3 | 92.13 | 94.43 | 95.02 | 95.51 | 97.43 |
| | | | Twiom | | |
| 15 | 94.98 | 95.81 | 96.79 | 97.06 | 97.31 |
| 12 | 95.80 | 96.27 | 96.67 | 96.88 | 97.21 |
| 9 | 95.66 | 96.12 | 97.15 | 97.34 | 97.39 |
| 6 | 95.32 | 95.55 | 96.80 | 97.98 | 98.14 |
| 3 | 93.06 | 93.21 | 95.28 | 97.53 | 98.25 |
| L.S.D. (5%)= | 0.31 | | | | |
| (1%)= | 0.41 | | | | |

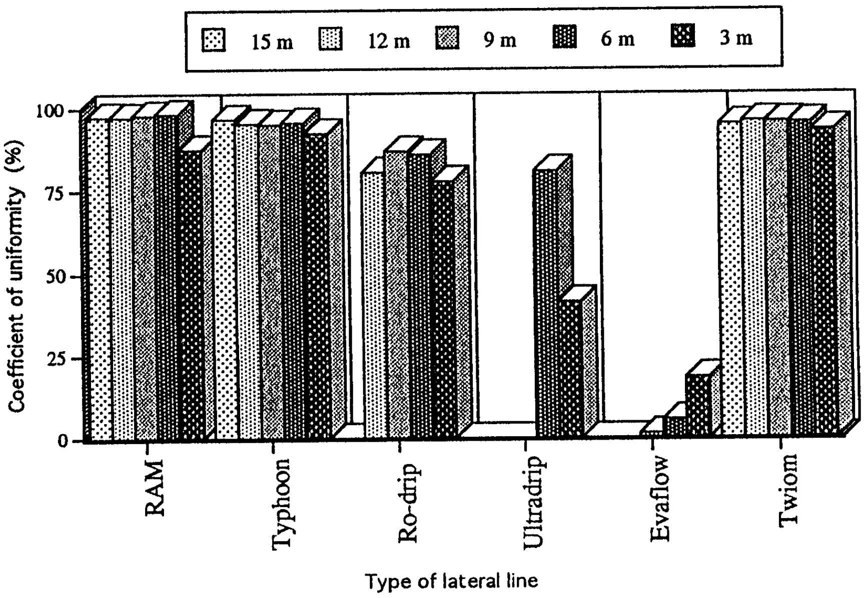


Fig. (4-35): Effect of type of lateral line and inlet pressure head on coefficient of uniformity at 2 % slope.

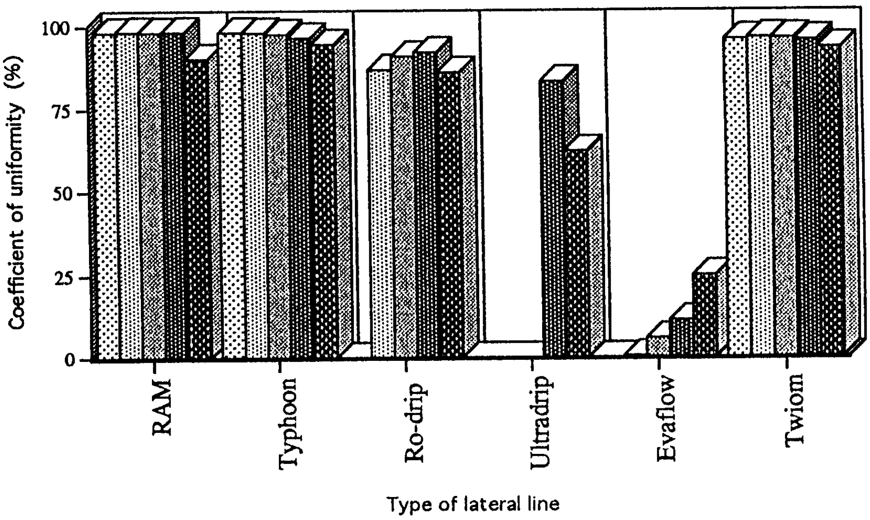


Fig. (4-36): Effect of type of lateral line and inlet pressure head on coefficient of uniformity at 1 % slope.

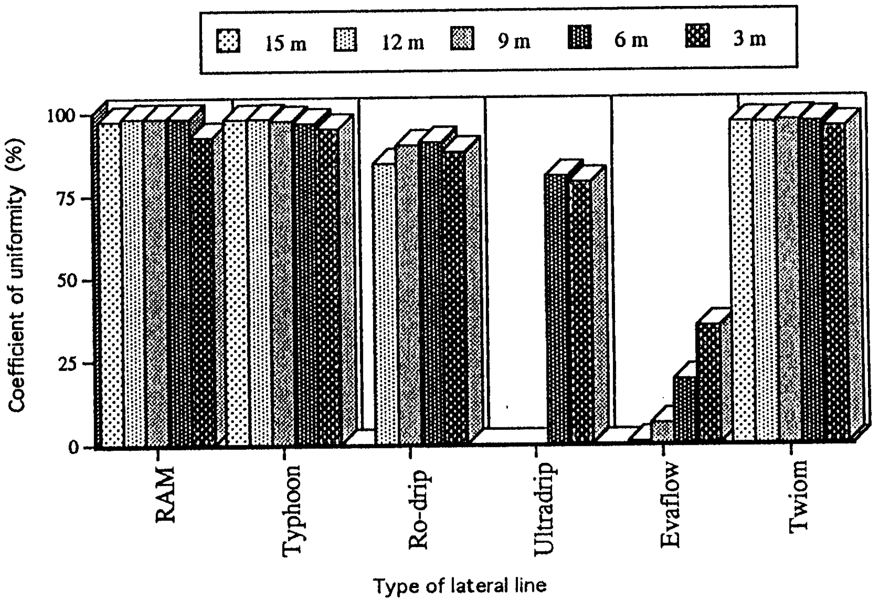


Fig. (4-37): Effect of type of lateral line and inlet pressure head on coefficient of uniformity at 0 % slope.

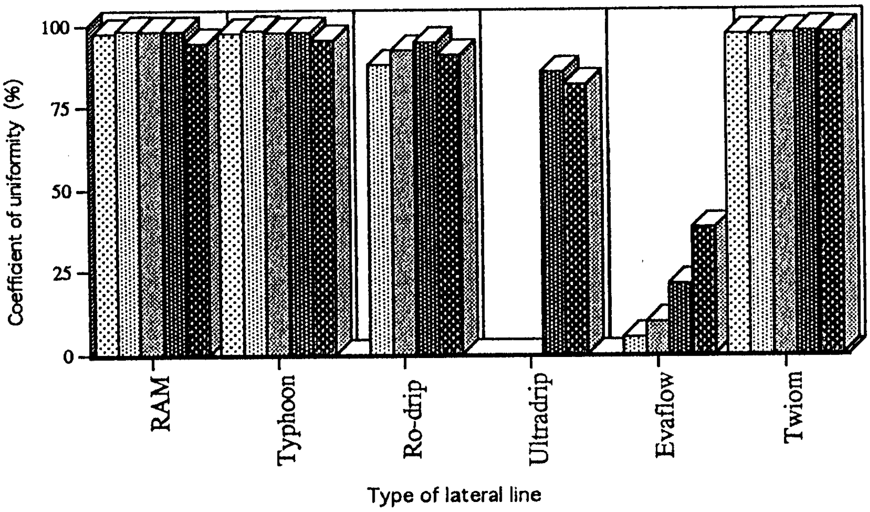


Fig. (4-38): Effect of type of lateral line and inlet pressure head on coefficient of uniformity at -1 % slope.

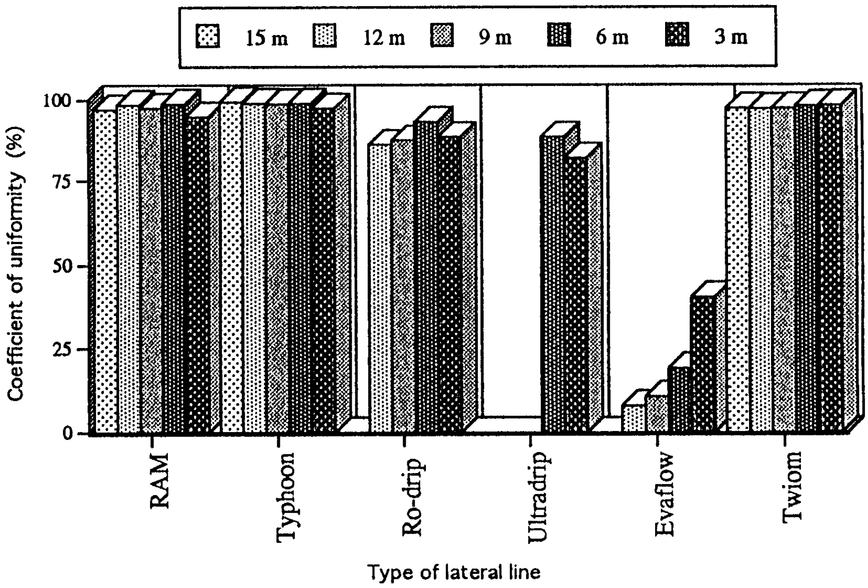


Fig. (4-39): Effect of type of lateral line and inlet pressure head on coefficient of uniformity at -2 % slope.

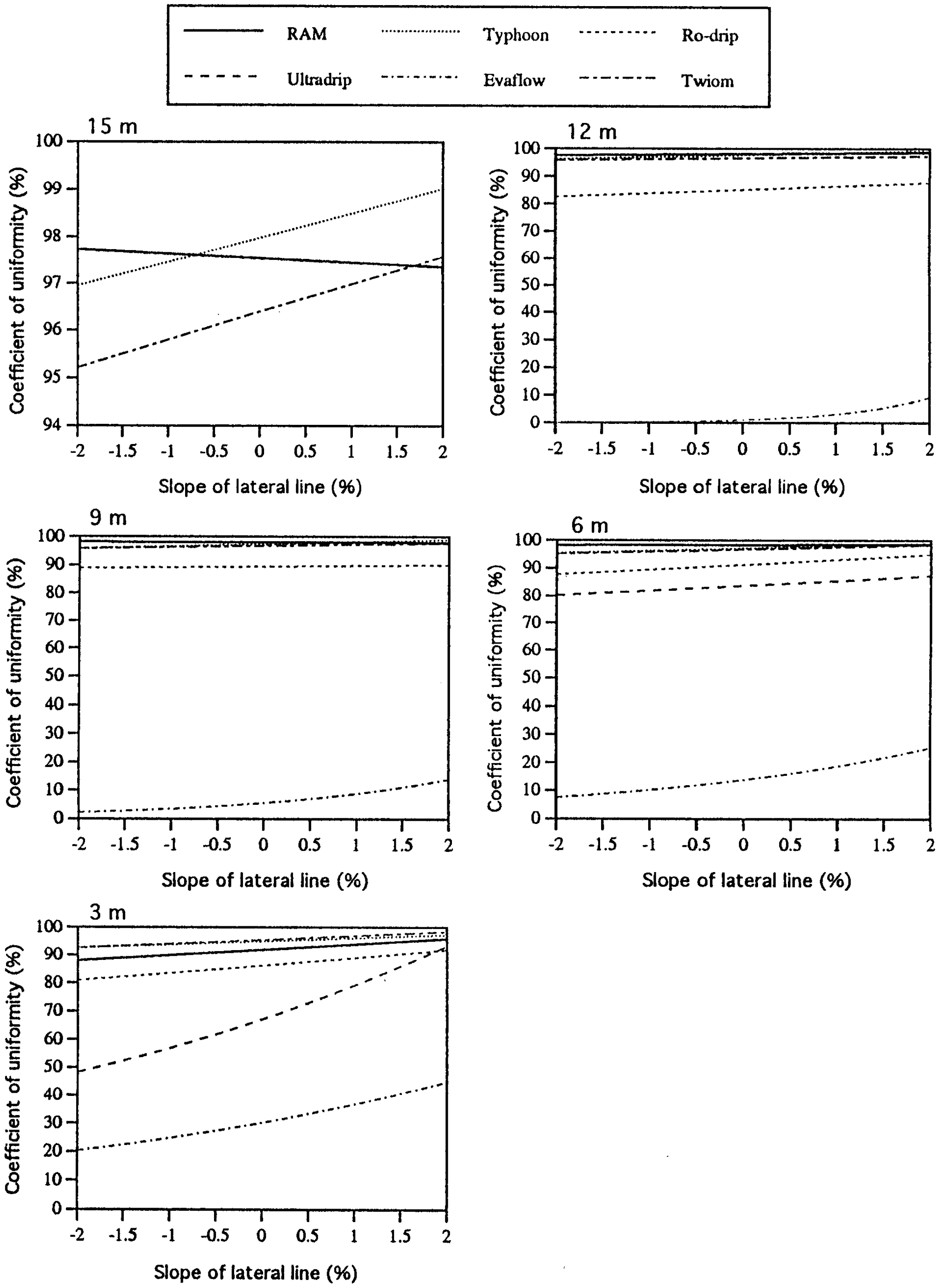


Fig. (4-40): Effect of type and slope of lateral line and inlet pressure head on coefficient of uniformity.

# 5-Appendix

Table (5-1): Analysis of variance of type and slope of lateral line and inlet pressure head on flow rate variation.

| (3*6*2*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V. | df | SS | MS | F | S |
| Rep. | 2 | 29.2674958 | 14.6337479 | 5.44981389 | |
| Lateral line (A) | 5 | 157186.83 | 31437.3661 | 11707.718 | * * |
| Error (a) | 10 | 26.8518306 | 2.68518306 | | |
| Inlet pressure (B) | 1 | 5866.01483 | 5866.01483 | 5182.45635 | * * |
| AxB | 5 | 3370.33138 | 674.066275 | 595.518278 | * * |
| Error (b) | 12 | 13.5827826 | 1.13189855 | | |
| Slope (C) | 4 | 5784.07769 | 1446.01942 | 710.587473 | * * |
| AxC | 20 | 1877.26358 | 93.8631788 | 46.1252443 | * * |
| BxC | 4 | 991.215641 | 247.80391 | 121.77316 | * * |
| AxBxC | 20 | 1132.82132 | 56.6410661 | 27.8339498 | * * |
| Error (c) | 96 | 195.356476 | 2.03496329 | | |
| Total | 179 | 176473.613 | | | |

| (3*5*4*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 17.3083671 | 8.65418354 | 3.79941887 | |
| Lateral line (A) | 4 | 312164.249 | 78041.0623 | 34262.1211 | * * |
| Error (a) | 8 | 18.2221205 | 2.27776506 | | |
| Inlet pressure (B) | 3 | 3185.83078 | 1061.94359 | 905.287324 | * * |
| AxB | 12 | 1849.18106 | 154.098421 | 131.366062 | * * |
| Error (b) | 30 | 35.1913773 | 1.17304591 | | |
| Slope (C) | 4 | 4913.03512 | 1228.25878 | 1679.87818 | * * |
| AxC | 16 | 1968.74325 | 123.046453 | 168.289497 | * * |
| BxC | 12 | 624.894681 | 52.0745567 | 71.22189 | * * |
| AxBxC | 48 | 656.954008 | 13.6865418 | 18.7189568 | * * |
| Error (c) | 160 | 116.985509 | 0.73115943 | | |
| Total | 299 | 325550.595 | | | |

| (3*3*5*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 5.23371738 | 2.61685869 | 0.648587 | |
| Lateral line (A) | 2 | 266.926388 | 133.463194 | 33.0787797 | * * |
| Error (a) | 4 | 16.1388292 | 4.0347073 | | |
| Inlet pressure (B) | 4 | 2804.63309 | 701.158273 | 643.207479 | * * |
| AxB | 8 | 958.090435 | 119.761304 | 109.863022 | * * |
| Error (b) | 24 | 26.1623179 | 1.09009658 | | |
| Slope (C) | 4 | 2266.09637 | 566.524093 | 870.855509 | * * |
| AxC | 8 | 563.65149 | 70.4564363 | 108.304971 | * * |
| BxC | 16 | 604.399442 | 37.7749651 | 58.0673213 | * * |
| AxBxC | 32 | 495.910251 | 15.4971954 | 23.822143 | * * |
| Error (c) | 120 | 78.0644899 | 0.65053742 | | |
| Total | 224 | 8085.30682 | | | |

Table (5-2): Average of emitter flow variation and pressure head variation at different type of lateral line.

| RAM | | Typhoon | | Twiom | | Ro-drip | | Evaflow | | Ultradrip | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $q_{var}$ | $h_{var}$ | $q_{var}$ | $h_{var}$ | $q_{var}$ | $h_{var}$ | $q_{var}$ | $h_{var}$ | $q_{var}$ | $h_{var}$ | $q_{var}$ | $h_{var}$ |
| 0.09 | 0.2 | 0.18 | 0.16 | 0.16 | 0.29 | - | - | - | - | - | - |
| 0.06 | 0.19 | 0.07 | 0.14 | 0.14 | 0.28 | - | - | - | - | - | - |
| 0.12 | 0.18 | 0.08 | 0.12 | 0.11 | 0.28 | - | - | - | - | - | - |
| 0.09 | 0.18 | 0.09 | 0.12 | 0.11 | 0.28 | - | - | - | - | - | - |
| 0.13 | 0.17 | 0.02 | 0.11 | 0.1 | 0.27 | - | - | - | - | - | - |
| 0.14 | 0.28 | 0.17 | 0.16 | 0.17 | 0.31 | 0.54 | 0.21 | 0.97 | 0.94 | - | - |
| 0.05 | 0.28 | 0.09 | 0.15 | 0.13 | 0.31 | 0.43 | 0.19 | 0.95 | 0.91 | - | - |
| 0.06 | 0.26 | 0.09 | 0.15 | 0.11 | 0.3 | 0.46 | 0.18 | 0.95 | 0.89 | - | - |
| 0.05 | 0.24 | 0.08 | 0.14 | 0.11 | 0.3 | 0.34 | 0.17 | 0.94 | 0.88 | - | - |
| 0.06 | 0.23 | 0.04 | 0.13 | 0.1 | 0.3 | 0.38 | 0.14 | 0.93 | 0.82 | - | - |
| 0.07 | 0.42 | 0.2 | 0.25 | 0.17 | 0.38 | 0.53 | 0.28 | 0.97 | 0.94 | - | - |
| 0.07 | 0.36 | 0.11 | 0.23 | 0.15 | 0.36 | 0.38 | 0.24 | 0.96 | 0.89 | - | - |
| 0.06 | 0.35 | 0.11 | 0.21 | 0.1 | 0.35 | 0.41 | 0.23 | 0.95 | 0.88 | - | - |
| 0.06 | 0.34 | 0.11 | 0.19 | 0.1 | 0.33 | 0.3 | 0.21 | 0.94 | 0.88 | - | - |
| 0.09 | 0.33 | 0.04 | 0.18 | 0.1 | 0.32 | 0.33 | 0.17 | 0.94 | 0.87 | - | - |
| 0.06 | 0.65 | 0.17 | 0.37 | 0.2 | 0.48 | 0.47 | 0.35 | 0.97 | 0.95 | 0.48 | 0.49 |
| 0.06 | 0.57 | 0.14 | 0.36 | 0.16 | 0.46 | 0.34 | 0.34 | 0.96 | 0.94 | 0.43 | 0.42 |
| 0.06 | 0.52 | 0.13 | 0.32 | 0.11 | 0.43 | 0.41 | 0.3 | 0.93 | 0.86 | 0.47 | 0.4 |
| 0.07 | 0.51 | 0.11 | 0.29 | 0.08 | 0.39 | 0.29 | 0.27 | 0.92 | 0.86 | 0.38 | 0.35 |
| 0.06 | 0.47 | 0.04 | 0.21 | 0.07 | 0.37 | 0.24 | 0.19 | 0.92 | 0.86 | 0.37 | 0.27 |
| 0.33 | 1 | 0.24 | 0.73 | 0.28 | 0.83 | 0.68 | 0.7 | 1 | 0.99 | 1 | 0.73 |
| 0.27 | 1 | 0.19 | 0.68 | 0.22 | 0.81 | 0.52 | 0.69 | 0.97 | 0.87 | 0.73 | 0.69 |
| 0.21 | 0.99 | 0.19 | 0.56 | 0.15 | 0.61 | 0.46 | 0.56 | 0.96 | 0.86 | 0.6 | 0.51 |
| 0.16 | 0.93 | 0.16 | 0.47 | 0.09 | 0.57 | 0.37 | 0.48 | 0.96 | 0.82 | 0.55 | 0.42 |
| 0.16 | 0.89 | 0.1 | 0.34 | 0.09 | 0.52 | 0.38 | 0.28 | 0.92 | 0.82 | 0.6 | 0.29 |

Table (5-3): Analysis of variance of type and slope of lateral line and inlet pressure head on pressure variation.

| (3*6*2*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V. | df | SS | MS | F | S |
| Rep. | 2 | 50.1676902 | 25.0838451 | 28.5131276 | |
| Lateral line (A) | 5 | 55776.1842 | 11155.2368 | 12680.3004 | * * |
| Error (a) | 10 | 8.79729697 | 0.8797297 | | |
| Inlet pressure (B) | 1 | 20410.1886 | 20410.1886 | 20218.7759 | * * |
| AxB | 5 | 8028.36413 | 1605.67283 | 1590.61436 | * * |
| Error (b) | 12 | 12.1136049 | 1.00946708 | | |
| Slope (C) | 4 | 12288.9927 | 3072.24818 | 3384.99123 | * * |
| AxC | 20 | 1710.40777 | 85.5203884 | 94.2260351 | * * |
| BxC | 4 | 1609.47804 | 402.369511 | 443.329179 | * |
| AxBxC | 20 | 1155.99939 | 57.7999694 | 63.683784 | * * |
| Error (c) | 96 | 87.1304548 | 0.9076089 | | |
| Total | 179 | 101137.824 | | | |

| (3*5*4*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 64.6306083 | 32.3153042 | 43.1686124 | |
| Lateral line (A) | 4 | 137133.824 | 34283.456 | 45797.781 | * * |
| Error (a) | 8 | 5.98866674 | 0.74858334 | | |
| Inlet pressure (B) | 3 | 58489.5428 | 19496.5143 | 18546.0671 | * * |
| AxB | 12 | 23198.5183 | 1933.20986 | 1838.96666 | * * |
| Error (b) | 30 | 31.5374374 | 1.05124791 | | |
| Slope (C) | 4 | 7091.95612 | 1772.98903 | 2193.39441 | * * |
| AxC | 16 | 649.36704 | 40.58544 | 50.2089274 | * * |
| BxC | 12 | 3288.07484 | 274.006237 | 338.977703 | * * |
| AxBxC | 48 | 1808.89331 | 37.6852773 | 46.6210876 | * * |
| Error (c) | 160 | 129.332984 | 0.80833115 | | |
| Total | 299 | 231891.666 | | | |

| (3*3*5*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 50.5682776 | 25.2841388 | 47.7444089 | |
| Lateral line (A) | 2 | 14345.6531 | 7172.82657 | 13544.5533 | * * |
| Error (a) | 4 | 2.11829107 | 0.52957277 | | |
| Inlet pressure (B) | 4 | 82219.6263 | 20554.9066 | 15408.1005 | * * |
| AxB | 8 | 8444.87858 | 1055.60982 | 791.292444 | * * |
| Error (b) | 24 | 32.0167796 | 1.33403248 | | |
| Slope (C) | 4 | 3505.28646 | 876.321614 | 862.780495 | * * |
| AxC | 8 | 167.507106 | 20.9383883 | 20.6148436 | * * |
| BxC | 16 | 2753.67474 | 172.104671 | 169.445271 | * * |
| AxBxC | 32 | 992.044373 | 31.0013867 | 30.5223462 | * * |
| Error (c) | 120 | 121.883369 | 1.01569474 | | |
| Total | 224 | 112635.257 | | | |

Table (5-4): Analysis of variance of type and slope of lateral line and inlet pressure head on distribution of uniformity.

(3*6*2*5)

| S.O.V. | df | SS | MS | F | S |
|---|---|---|---|---|---|
| Rep. | 2 | 9.02426327 | 4.51213163 | 3.92391346 | |
| Lateral line (A) | 5 | 110663.75 | 22132.75 | 19247.4429 | * * |
| Error (a) | 10 | 11.49906 | 1.149906 | | |
| Inlet pressure (B) | 1 | 2191.51901 | 2191.51901 | 1423.86687 | * * |
| AxB | 5 | 1459.76323 | 291.952645 | 189.686558 | * * |
| Error (b) | 12 | 18.4695836 | 1.53913197 | | |
| Slope (C) | 4 | 3656.08853 | 914.022133 | 797.440136 | * * |
| AxC | 20 | 1810.77963 | 90.5389814 | 78.9908854 | * * |
| BxC | 4 | 967.933973 | 241.983493 | 211.118903 | * * |
| AxBxC | 20 | 1096.63426 | 54.8317132 | 47.8380197 | * * |
| Error (c) | 96 | 110.034748 | 1.1461953 | | |
| Total | 179 | 121995.496 | | | |

(3*5*4*5)

| S.O.V | df | SS | MS | F | S |
|---|---|---|---|---|---|
| Rep. | 2 | 3.55062881 | 1.7753144 | 2.04954028 | |
| Lateral line (A) | 4 | 226925.032 | 56731.258 | 65494.3136 | * * |
| Error (a) | 8 | 6.9296102 | 0.86620128 | | |
| Inlet pressure (B) | 3 | 959.612515 | 319.870838 | 679.447108 | * * |
| AxB | 12 | 297.370364 | 24.7808637 | 52.6377654 | * * |
| Error (b) | 30 | 14.1234322 | 0.47078107 | | |
| Slope (C) | 4 | 1738.79257 | 434.698143 | 951.444759 | * * |
| AxC | 16 | 929.807746 | 58.1129841 | 127.194687 | * * |
| BxC | 12 | 734.192256 | 61.182688 | 133.913495 | * * |
| AxBxC | 48 | 612.542387 | 12.7612997 | 27.9312712 | * * |
| Error (c) | 160 | 73.1011467 | 0.45688217 | | |
| Total | 299 | 232295.055 | | | |

(3*3*5*5)

| S.O.V | df | SS | MS | F | S |
|---|---|---|---|---|---|
| Rep. | 2 | 0.42135485 | 0.21067742 | 0.52790814 | |
| Lateral line (A) | 2 | 7.84502018 | 3.92251009 | 9.82888896 | * * |
| Error (a) | 4 | 1.59631881 | 0.3990797 | | |
| Inlet pressure (B) | 4 | 541.403574 | 135.350894 | 1342.72693 | * * |
| AxB | 8 | 191.053551 | 23.8816939 | 236.914532 | * * |
| Error (b) | 24 | 2.41927183 | 0.10080299 | | |
| Slope (C) | 4 | 334.195213 | 83.5488032 | 1044.50146 | * * |
| AxC | 8 | 80.9613887 | 10.1201736 | 126.5193 | * * |
| BxC | 16 | 139.585532 | 8.72409573 | 109.065964 | * * |
| AxBxC | 32 | 99.9518736 | 3.12349605 | 39.0489878 | * * |
| Error (c) | 120 | 9.59870017 | 0.07998917 | | |
| Total | 224 | 1409.0318 | | | |

Table (5-5): Analysis of variance of type and slope of lateral line and inlet pressure head on pressure head losses.

| | | (3*6*2*5) | | | |
|---|---|---|---|---|---|
| S.O.V. | df | SS | MS | F | S |
| Rep. | 2 | 0.08472834 | 0.04236417 | 5.4730922 | |
| Lateral line (A) | 5 | 122.955804 | 24.5911608 | 3176.96968 | * * |
| Error (a) | 10 | 0.07740446 | 0.00774045 | | |
| Inlet pressure (B) | 1 | 27.8047501 | 27.8047501 | 3635.83829 | * * |
| AxB | 5 | 37.042275 | 7.40845501 | 968.753333 | * * |
| Error (b) | 12 | 0.09176893 | 0.00764741 | | |
| Slope (C) | 4 | 19.2737049 | 4.81842621 | 1000.877 | * * |
| AxC | 20 | 2.18848288 | 0.10942414 | 22.7294357 | * * |
| BxC | 4 | 0.06217072 | 0.01554268 | 3.22850465 | * |
| AxBxC | 20 | 1.19667394 | 0.0598337 | 12.4285749 | * * |
| Error (c) | 96 | 0.4621636 | 0.0048142 | | |
| Total | 179 | 211.239927 | | | |
| | | (3*5*4*5) | | | |
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 0.44696099 | 0.22348049 | 53.3050192 | |
| Lateral line (A) | 4 | 950.68866 | 237.672165 | 56690.0454 | * * |
| Error (a) | 8 | 0.03353988 | 0.00419248 | | |
| Inlet pressure (B) | 3 | 183.933398 | 61.3111327 | 3475.97812 | * * |
| AxB | 12 | 378.684291 | 31.5570242 | 1789.09638 | * * |
| Error (b) | 30 | 0.5291558 | 0.01763853 | | |
| Slope (C) | 4 | 20.577442 | 5.14436051 | 629.511549 | * * |
| AxC | 16 | 1.232854 | 0.07705337 | 9.42896388 | * * |
| BxC | 12 | 0.82315029 | 0.06859586 | 8.39402376 | * * |
| AxBxC | 48 | 3.72700048 | 0.07764584 | 9.50146379 | * * |
| Error (c) | 160 | 1.307518 | 0.00817199 | | |
| Total | 299 | 1541.98397 | | | |
| | | (3*3*5*5) | | | |
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 0.36421123 | 0.18210561 | 21.3113982 | |
| Lateral line (A) | 2 | 77.8388523 | 38.9194262 | 4554.65031 | * * |
| Error (a) | 4 | 0.03417995 | 0.00854499 | | |
| Inlet pressure (B) | 4 | 16.9705012 | 4.24262529 | 168.174504 | * * |
| AxB | 8 | 31.0966751 | 3.88708439 | 154.081128 | * * |
| Error (b) | 24 | 0.60546043 | 0.02522752 | | |
| Slope (C) | 4 | 11.0189971 | 2.75474928 | 157.254763 | * * |
| AxC | 8 | 0.34558863 | 0.04319858 | 2.46598932 | * * |
| BxC | 16 | 1.50463065 | 0.09403942 | 5.36823664 | * * |
| AxBxC | 32 | 1.69652346 | 0.05301636 | 3.02643689 | * * |
| Error (c) | 120 | 2.10212973 | 0.01751775 | | |
| Total | 224 | 143.57775 | | | |

Table (5-6):Average of head losses in m at different inlet pressure head and slope of lateral line

| Inlet pressure head, m | Slope of lateral line, % | RAM | Typhoon | Twiom | Ro-drip | Evaflow |
|---|---|---|---|---|---|---|
| 15 | -2 | 2.96 | 2.37 | 4.31 | - | - |
| 15 | -1 | 2.91 | 2.06 | 4.24 | - | - |
| 15 | 0 | 2.76 | 1.86 | 4.2 | - | - |
| 15 | 1 | 2.69 | 1.79 | 4.15 | - | - |
| 15 | 2 | 2.58 | 1.71 | 4.06 | - | - |
| 12 | -2 | 3.4 | 1.92 | 3.72 | 2.47 | 11.23 |
| 12 | -1 | 3.31 | 1.85 | 3.67 | 2.26 | 10.87 |
| 12 | 0 | 3.06 | 1.79 | 3.64 | 2.14 | 10.67 |
| 12 | 1 | 2.86 | 1.71 | 3.62 | 2.01 | 10.6 |
| 12 | 2 | 2.8 | 1.6 | 3.6 | 1.68 | 9.78 |
| 9 | -2 | 3.82 | 2.25 | 3.38 | 2.48 | 8.43 |
| 9 | -1 | 3.22 | 2.07 | 3.23 | 2.17 | 8.05 |
| 9 | 0 | 3.15 | 1.9 | 3.13 | 2.03 | 7.96 |
| 9 | 1 | 3.05 | 1.72 | 2.98 | 1.89 | 7.9 |
| 9 | 2 | 2.98 | 1.63 | 2.92 | 1.5 | 7.87 |
| 6 | -2 | 3.88 | 2.19 | 2.9 | 2.08 | 5.7 |
| 6 | -1 | 3.39 | 2.15 | 2.77 | 2.01 | 5.65 |
| 6 | 0 | 3.12 | 1.89 | 2.58 | 1.83 | 5.19 |
| 6 | 1 | 3.03 | 1.72 | 2.36 | 1.63 | 5.18 |
| 6 | 2 | 2.84 | 1.27 | 2.21 | 1.13 | 5.14 |
| 3 | -2 | 3 | 2.19 | 2.5 | 2.11 | 2.97 |
| 3 | -1 | 2.99 | 2.03 | 2.43 | 2.06 | 2.61 |
| 3 | 0 | 2.98 | 1.69 | 1.84 | 1.68 | 2.57 |
| 3 | 1 | 2.78 | 1.4 | 1.71 | 1.43 | 2.47 |
| 3 | 2 | 2.65 | 1.03 | 1.57 | 0.85 | 2.45 |

Table (5-7):Average of coefficient of uniformity at different of inlet pressure head and slope of lateral line

| Inlet pressure head, m | Slope of lateral line, % | RAM | Typhoon | Twiom | Ro-drip | Evaflow |
|---|---|---|---|---|---|---|
| 15 | -2 | 97.30 | 96.64 | 94.98 | - | - |
| 15 | -1 | 98.15 | 98.10 | 95.81 | - | - |
| 15 | 0 | 97.54 | 98.03 | 96.79 | - | - |
| 15 | 1 | 97.67 | 97.71 | 97.06 | - | - |
| 15 | 2 | 97.07 | 99.43 | 97.31 | - | - |
| 12 | -2 | 97.15 | 95.26 | 95.80 | 80.41 | 0.00 |
| 12 | -1 | 98.31 | 97.95 | 96.27 | 86.73 | 0.43 |
| 12 | 0 | 98.36 | 98.12 | 96.67 | 84.54 | 0.71 |
| 12 | 1 | 98.34 | 98.35 | 96.88 | 87.86 | 5.20 |
| 12 | 2 | 98.41 | 98.94 | 97.21 | 86.09 | 7.92 |
| 9 | -2 | 97.87 | 94.88 | 95.66 | 86.69 | 1.36 |
| 9 | -1 | 98.10 | 97.49 | 96.12 | 90.77 | 5.80 |
| 9 | 0 | 98.24 | 97.52 | 97.15 | 90.04 | 6.17 |
| 9 | 1 | 98.19 | 97.78 | 97.34 | 92.26 | 9.74 |
| 9 | 2 | 97.57 | 98.74 | 97.39 | 87.38 | 10.66 |
| 6 | -2 | 98.34 | 95.48 | 95.32 | 85.70 | 5.64 |
| 6 | -1 | 98.22 | 96.39 | 95.55 | 91.92 | 11.29 |
| 6 | 0 | 98.35 | 96.73 | 96.80 | 90.97 | 19.28 |
| 6 | 1 | 98.30 | 97.93 | 97.98 | 94.78 | 21.08 |
| 6 | 2 | 98.67 | 98.98 | 98.14 | 93.18 | 19.13 |
| 3 | -2 | 87.24 | 92.13 | 93.06 | 77.67 | 18.52 |
| 3 | -1 | 90.09 | 94.43 | 93.21 | 86.06 | 24.88 |
| 3 | 0 | 92.57 | 95.02 | 95.28 | 87.99 | 35.17 |
| 3 | 1 | 94.56 | 95.51 | 97.53 | 90.96 | 38.20 |
| 3 | 2 | 94.84 | 97.43 | 98.25 | 88.57 | 40.32 |

Table (5-8): Analysis of variance of type and slope of lateral line and inlet pressure head on coefficient of uniformity.

| (3*6*2*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V. | df | SS | MS | F | S |
| Rep. | 2 | 11.7780642 | 5.88903212 | 3.54146507 | |
| Lateral line (A) | 5 | 121198.139 | 24239.6279 | 14576.8937 | * * |
| Error (a) | 10 | 16.6288019 | 1.66288019 | | |
| Inlet pressure (B) | 1 | 224.538922 | 224.538922 | 99.3447965 | * * |
| AxB | 5 | 3857.30734 | 771.461469 | 341.324711 | * * |
| Error (b) | 12 | 27.1223774 | 2.26019811 | | |
| Slope (C) | 4 | 2814.82081 | 703.705203 | 787.049547 | * * |
| AxC | 20 | 1670.13367 | 83.5066835 | 93.3969184 | * * |
| BxC | 4 | 605.054185 | 151.263546 | 169.178663 | * * |
| AxBxC | 20 | 1054.09084 | 52.7045422 | 58.9466809 | * * |
| Error (c) | 96 | 85.8341127 | 0.89410534 | | |
| Total | 179 | 131565.448 | | | |

| (3*5*4*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 2.45181271 | 1.22590636 | 2.37788653 | |
| Lateral line (A) | 4 | 314355.362 | 78588.8405 | 152438.516 | * * |
| Error (a) | 8 | 4.12435611 | 0.51554451 | | |
| Inlet pressure (B) | 3 | 815.064427 | 271.688142 | 634.231966 | * * |
| AxB | 12 | 7506.2469 | 625.520575 | 1460.22252 | * * |
| Error (b) | 30 | 12.8512038 | 0.42837346 | | |
| Slope (C) | 4 | 1424.1789 | 356.044725 | 1182.36287 | * * |
| AxC | 16 | 913.34158 | 57.0838488 | 189.565577 | * * |
| BxC | 12 | 327.706515 | 27.3088762 | 90.6880488 | * * |
| AxBxC | 48 | 245.431035 | 5.11314656 | 16.9798743 | * * |
| Error (c) | 160 | 48.1807719 | 0.30112982 | | |
| Total | 299 | 325654.94 | | | |

| (3*3*5*5) | | | | | |
|---|---|---|---|---|---|
| S.O.V | df | SS | MS | F | S |
| Rep. | 2 | 0.24821571 | 0.12410786 | 1.04491083 | |
| Lateral line (A) | 2 | 14.563884 | 7.281942 | 61.3094155 | * * |
| Error (a) | 4 | 0.47509453 | 0.11877363 | | |
| Inlet pressure (B) | 4 | 393.333386 | 98.3333466 | 2026.9844 | * * |
| AxB | 8 | 171.649533 | 21.4561916 | 442.285016 | * * |
| Error (b) | 24 | 1.16429131 | 0.04851214 | | |
| Slope (C) | 4 | 205.39342 | 51.348355 | 1385.42018 | * * |
| AxC | 8 | 26.5372626 | 3.31715783 | 89.4996032 | * * |
| BxC | 16 | 95.3326415 | 5.9582901 | 160.759489 | * * |
| AxBxC | 32 | 42.8524421 | 1.33913882 | 36.1310492 | * * |
| Error (c) | 120 | 4.44760564 | 0.03706338 | | |
| Total | 224 | 955.997777 | | | |

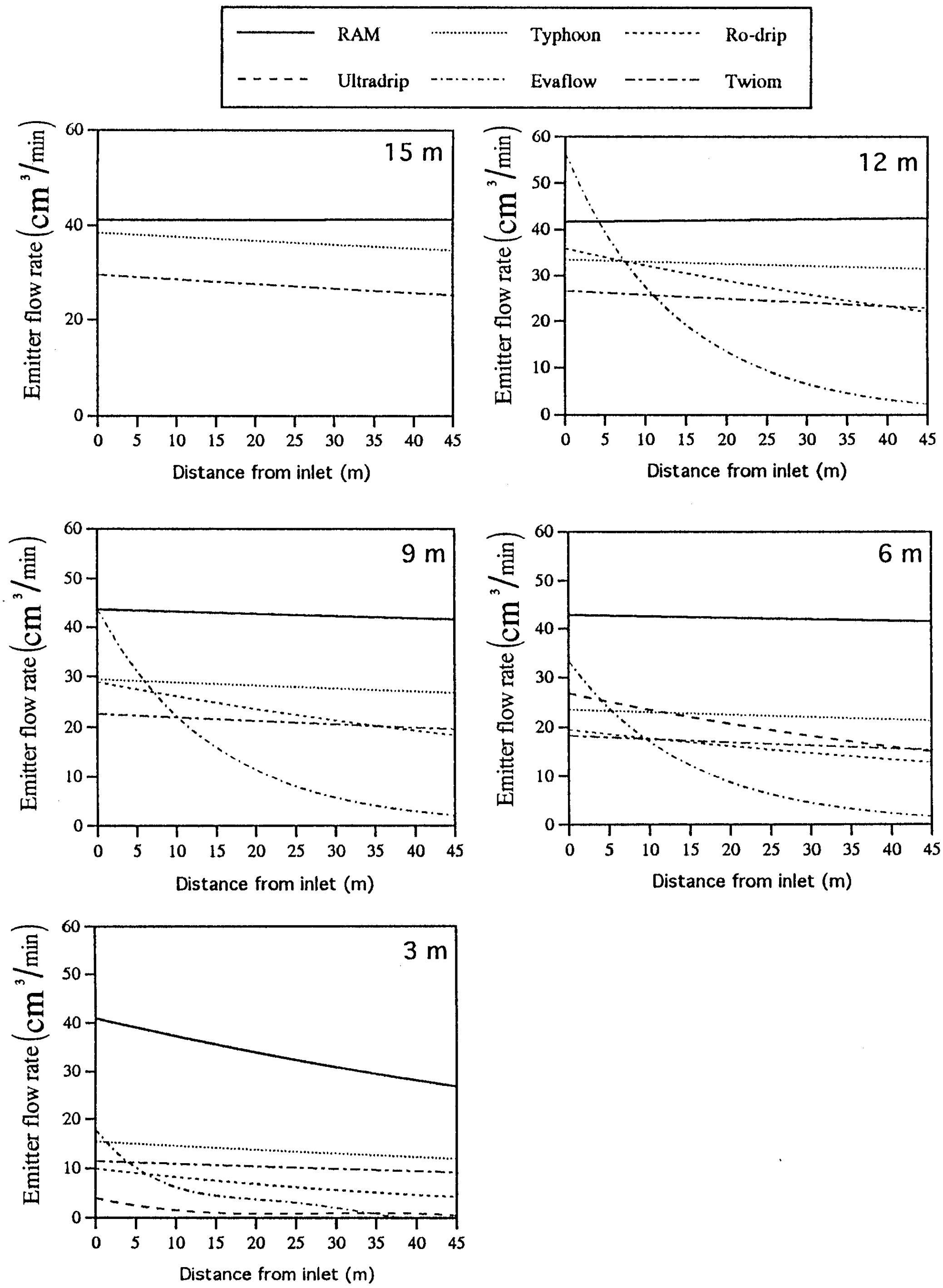


Fig. (5-1):Effect of type of lateral line and inlet pressure head on emitter flow rate at -2 % slope.

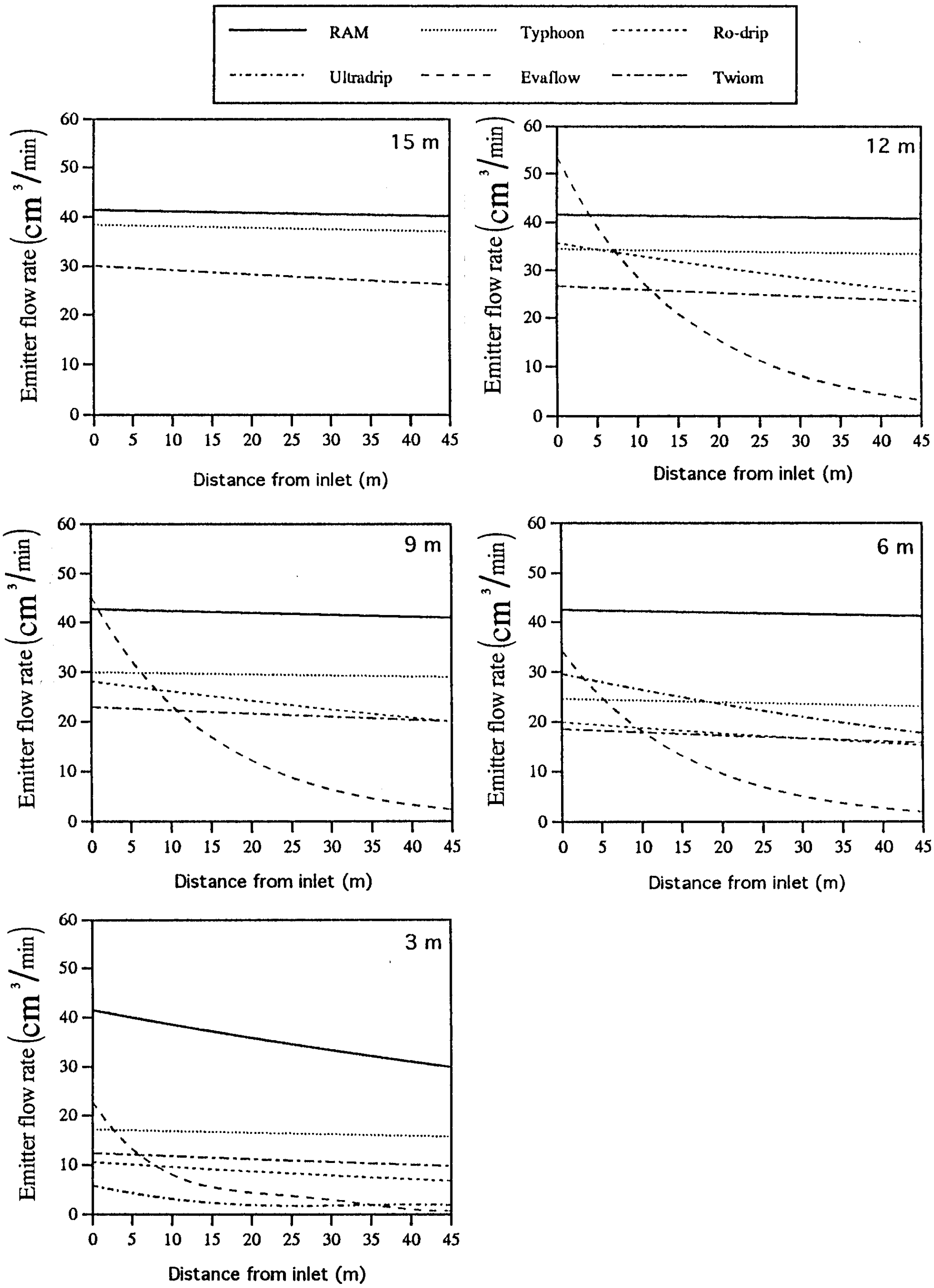


Fig. (5-2):Effect of type of lateral line and inlet pressure head on emitter flow rate at -1 % slope.

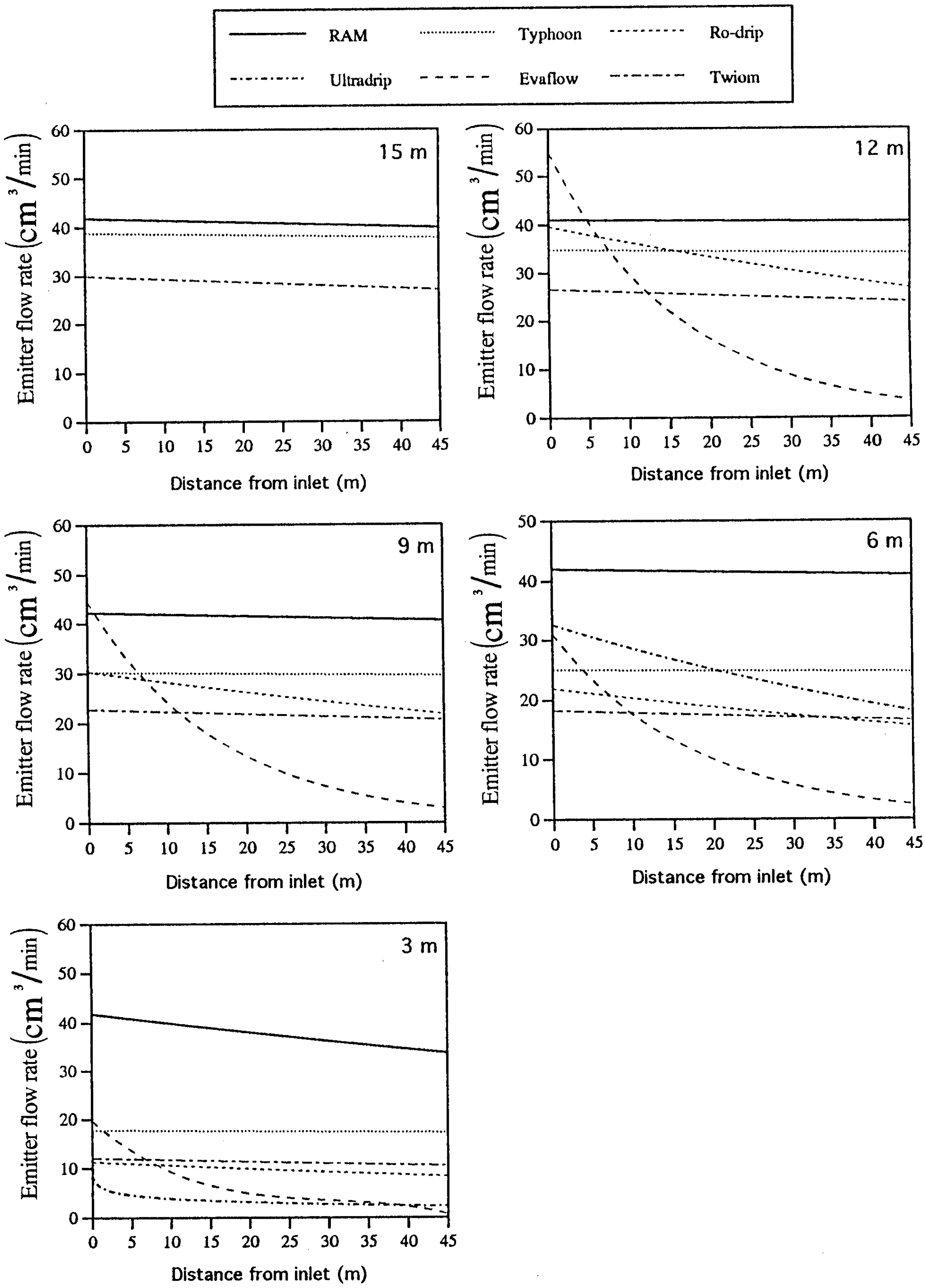


Fig. (5-3):Effect of type of lateral line and inlet pressure head on emitter flow rate at 0 % slope.

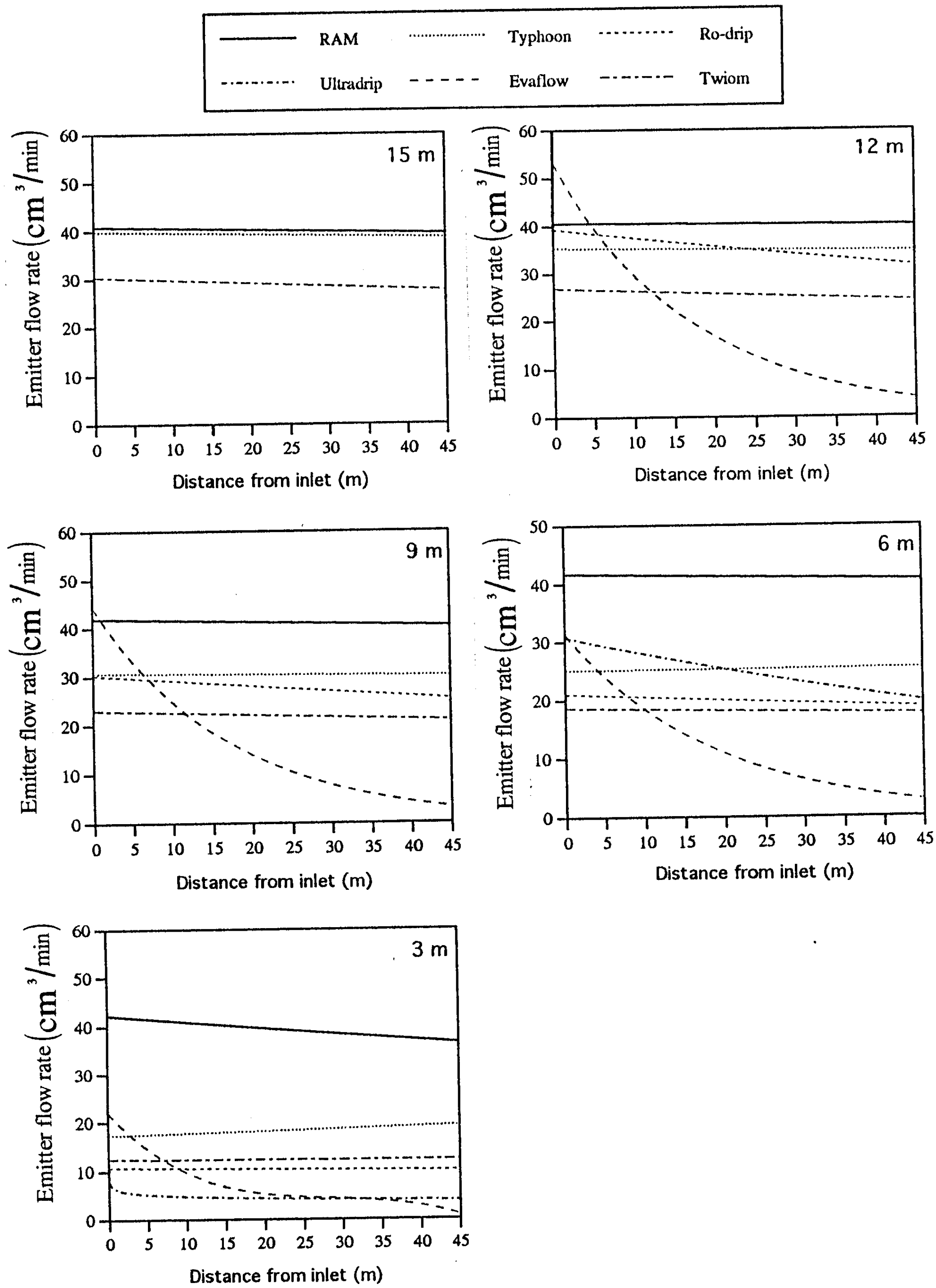


Fig. (5-4): Effect of type of lateral line and inlet pressure head on emitter flow rate at 1 % slope.

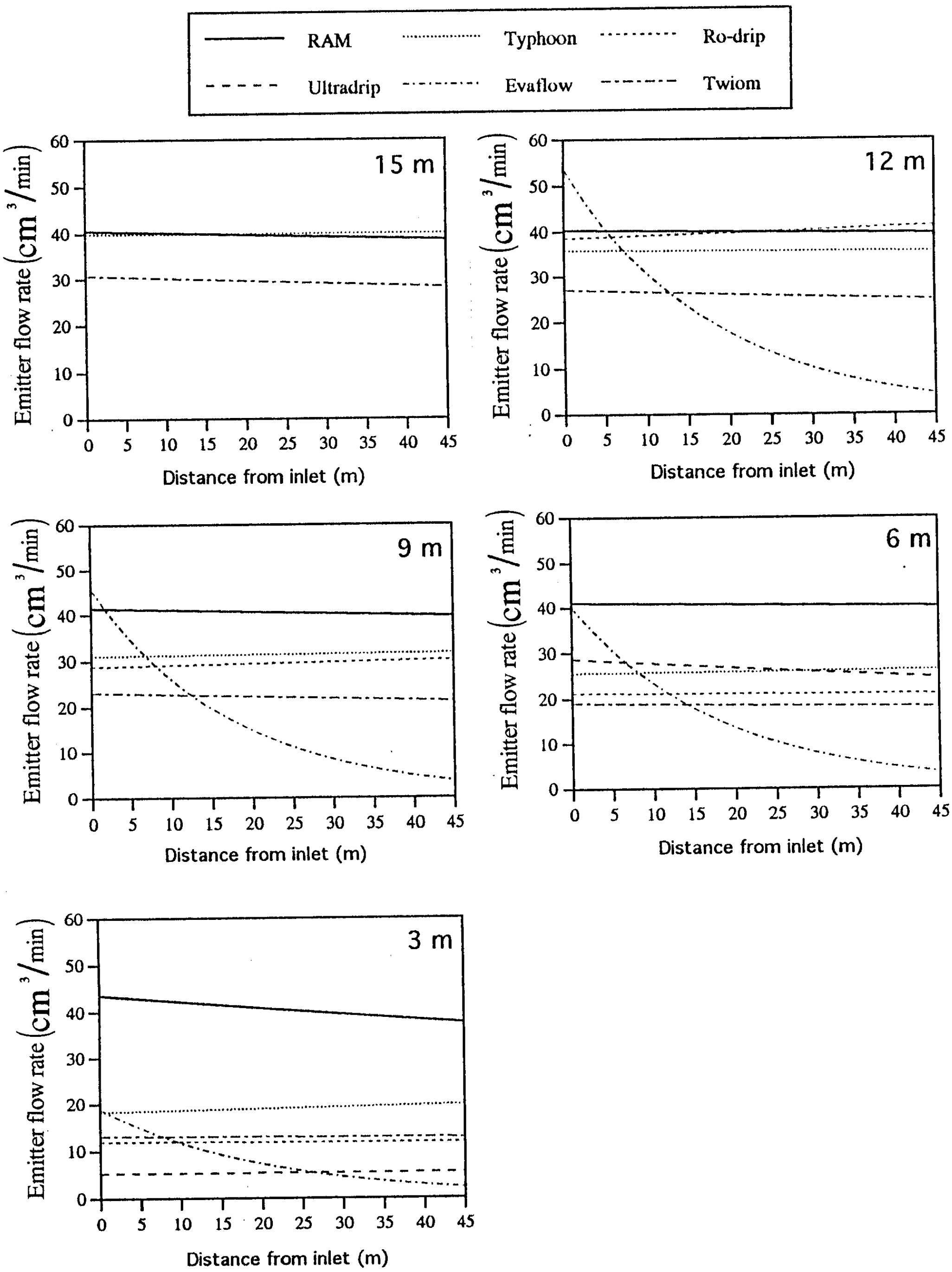


Fig. (5-5): Effect of type of lateral lineand inlet pressure head on emitter flow rate at 2% slope.

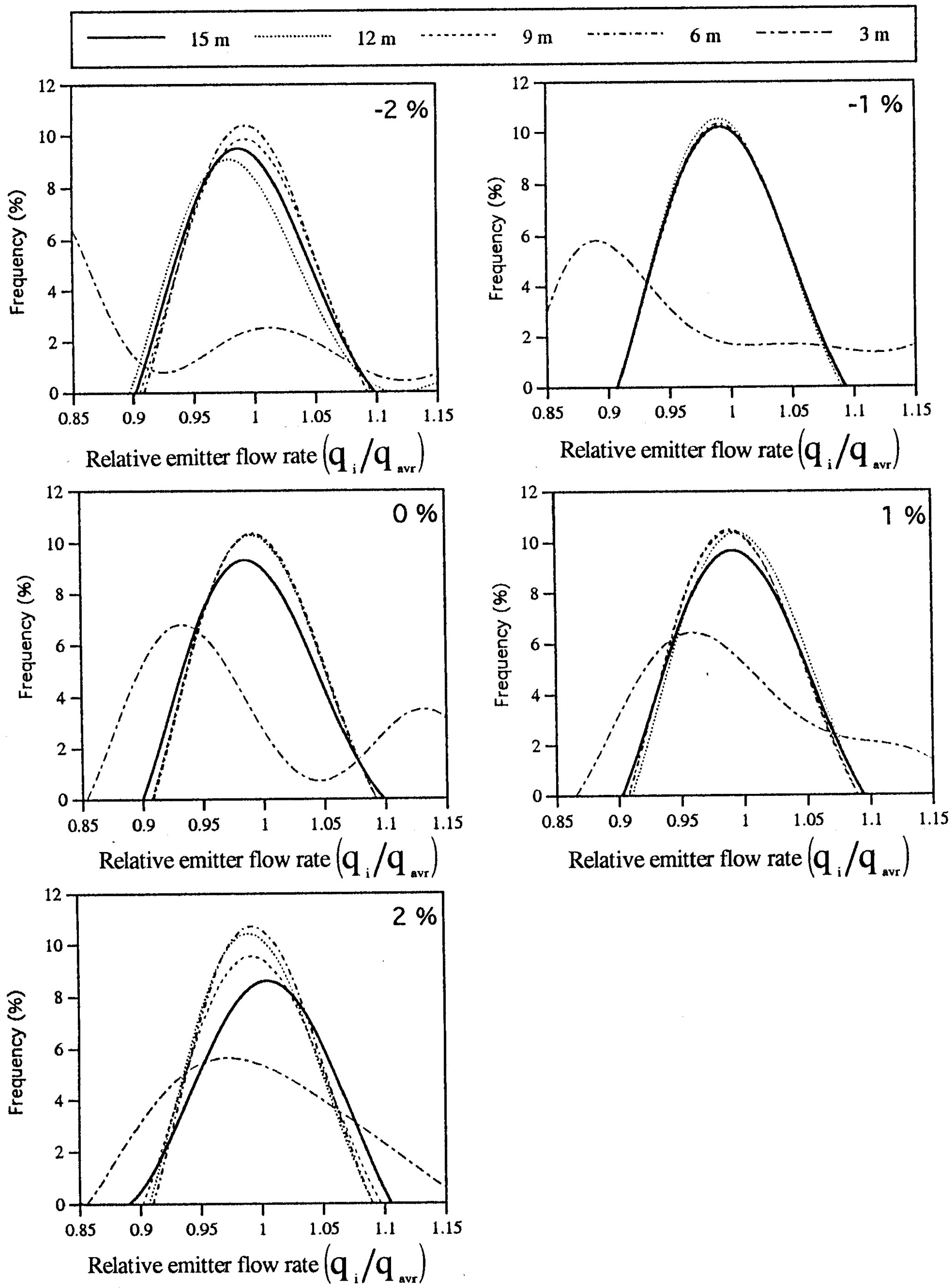


Fig. (5-6): Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in RAM.

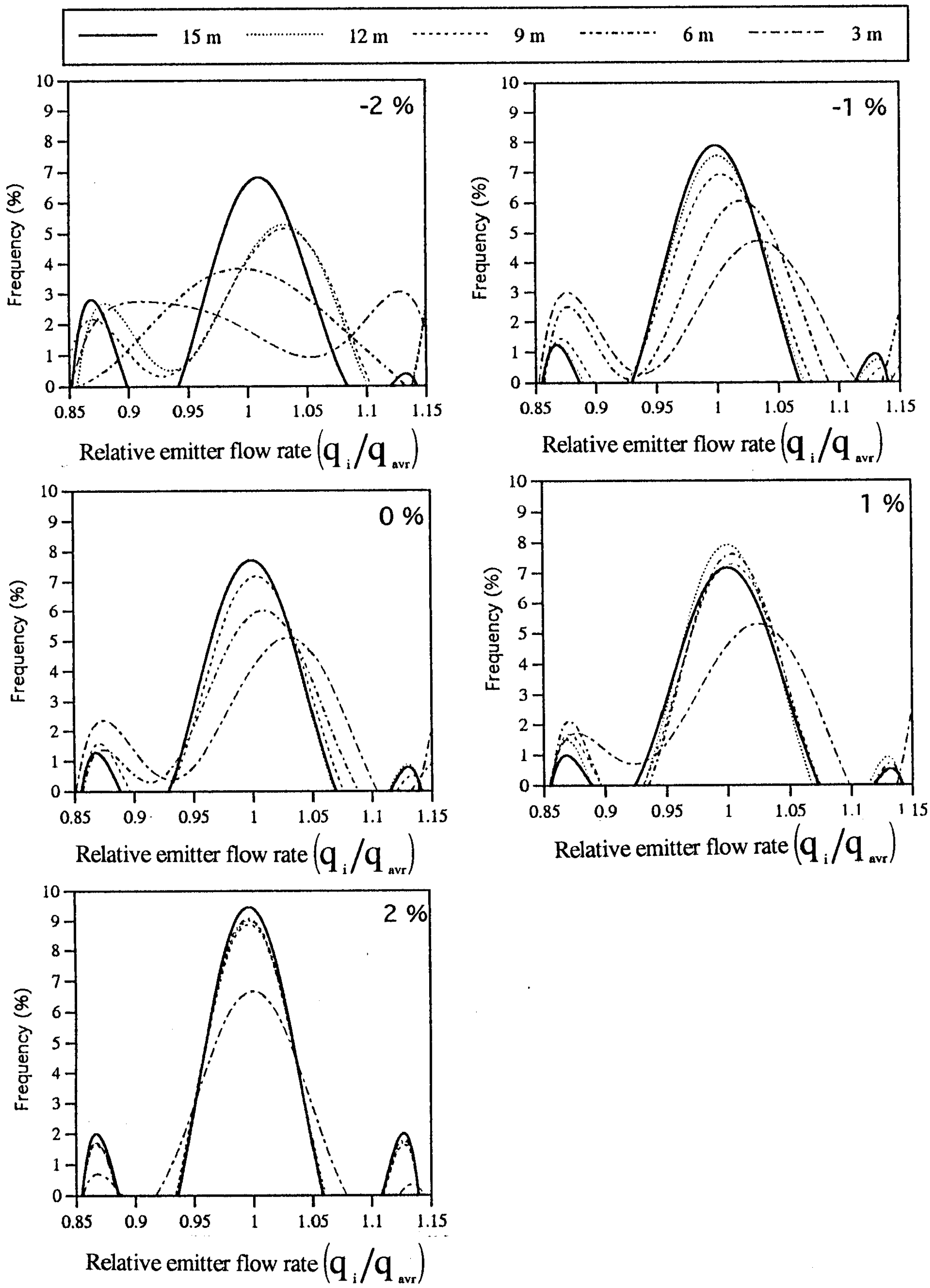


Fig. (5-7):Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in Typhoon.

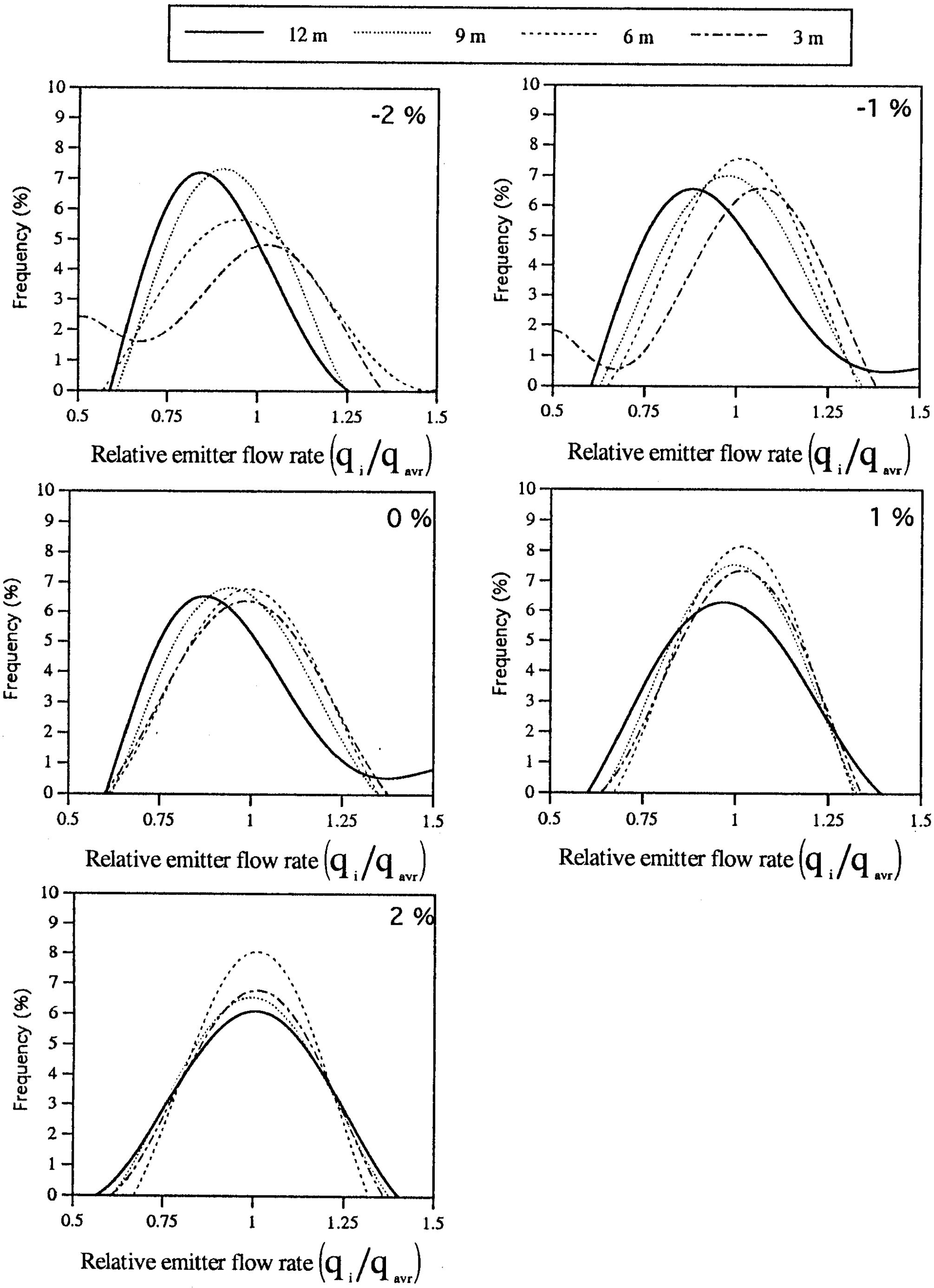


Fig. (5-8): Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in Ro-drip.

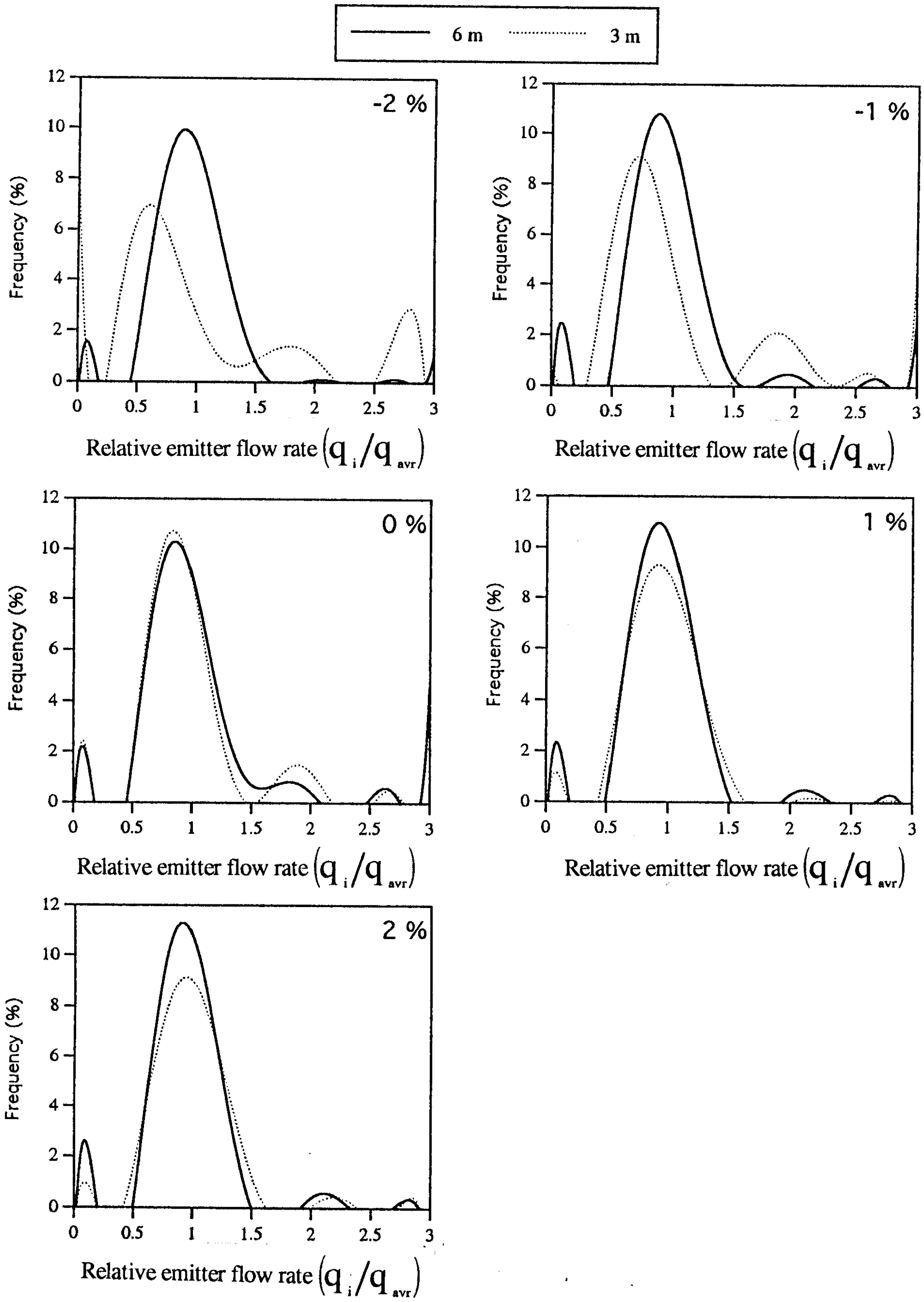


Fig. (5-9): Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in Ultradrip.

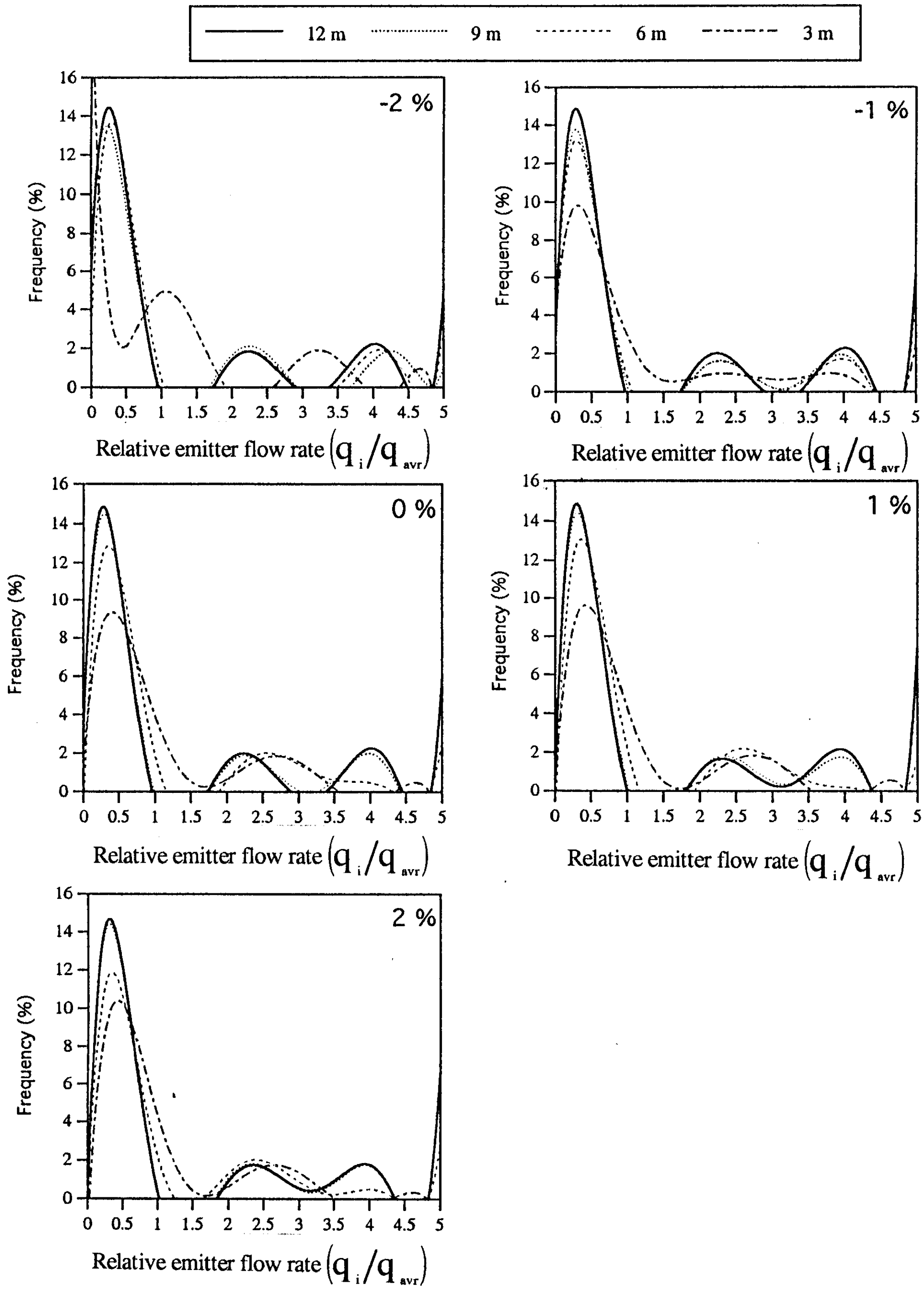


Fig. (5-10): **Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in Evaflow.**

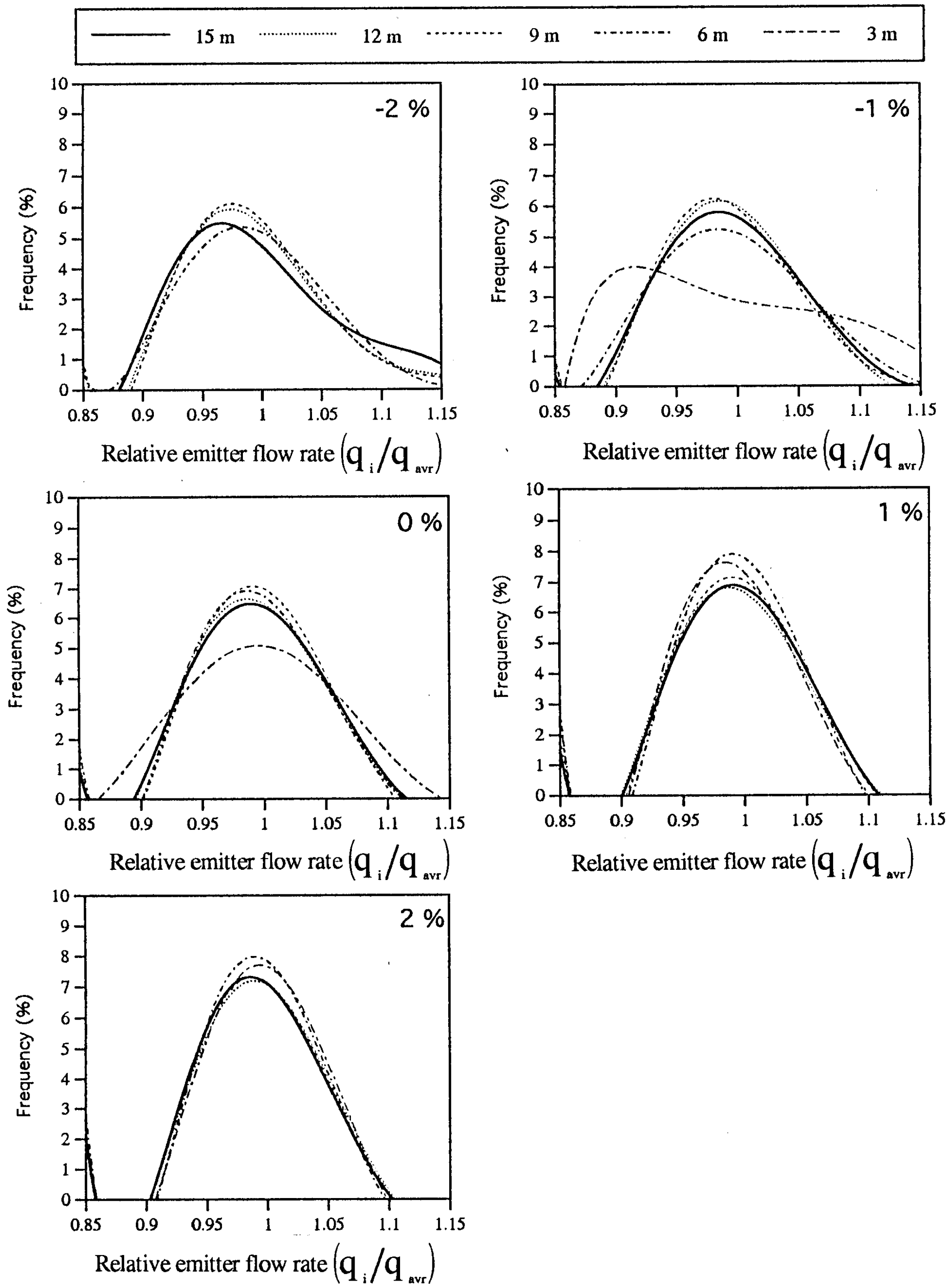


Fig. (5-11): Effect of inlet pressure head on relative emitter flow rate at different slope of lateral line in Twiom.

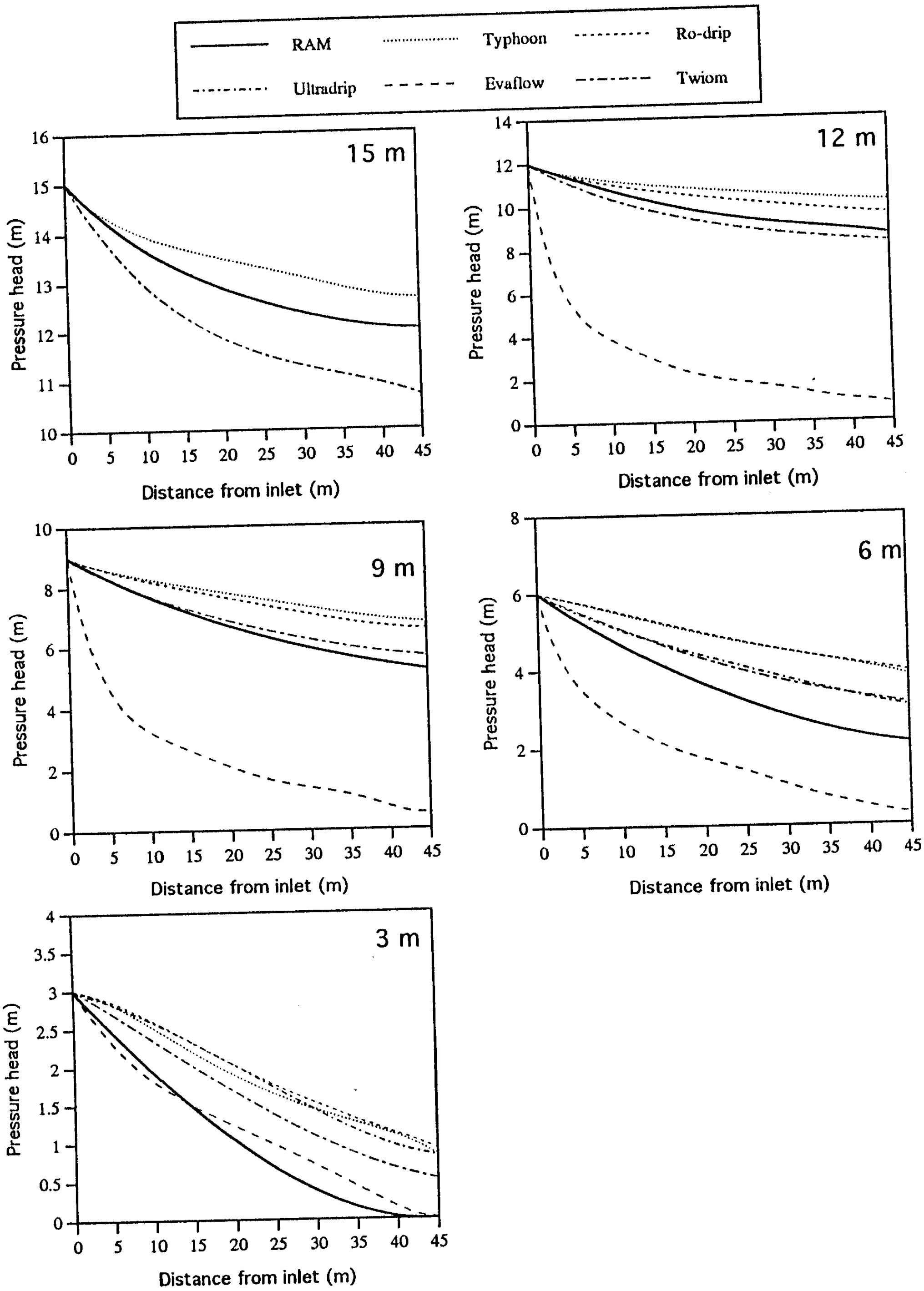


Fig. (5-12): Effect of type of lateral line and inlet pressure head on pressure head distribution at -2 % slope.

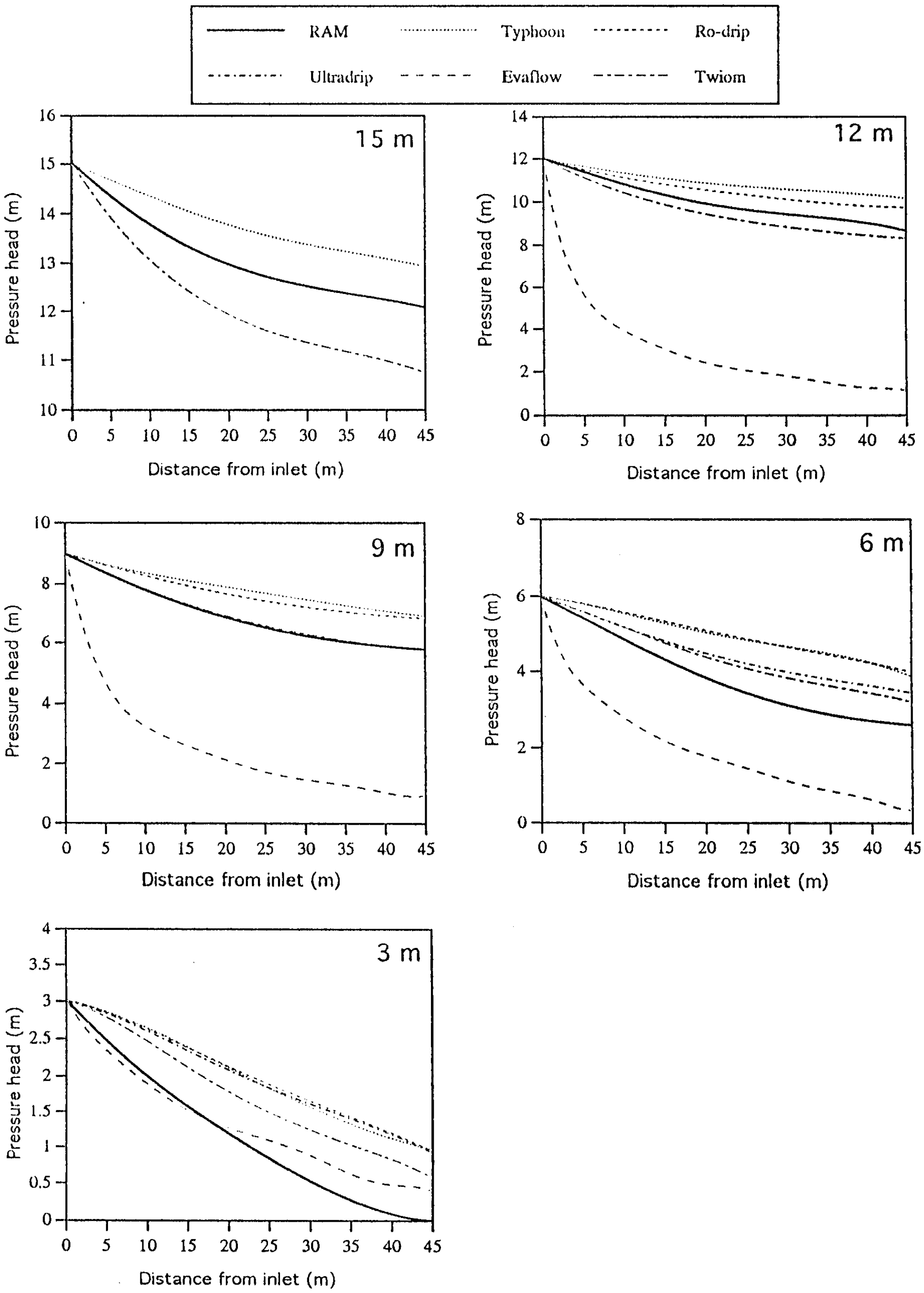


Fig. (5-13): Effect of type of lateral line and inlet pressure head on pressure head distribution at -1 % slope.

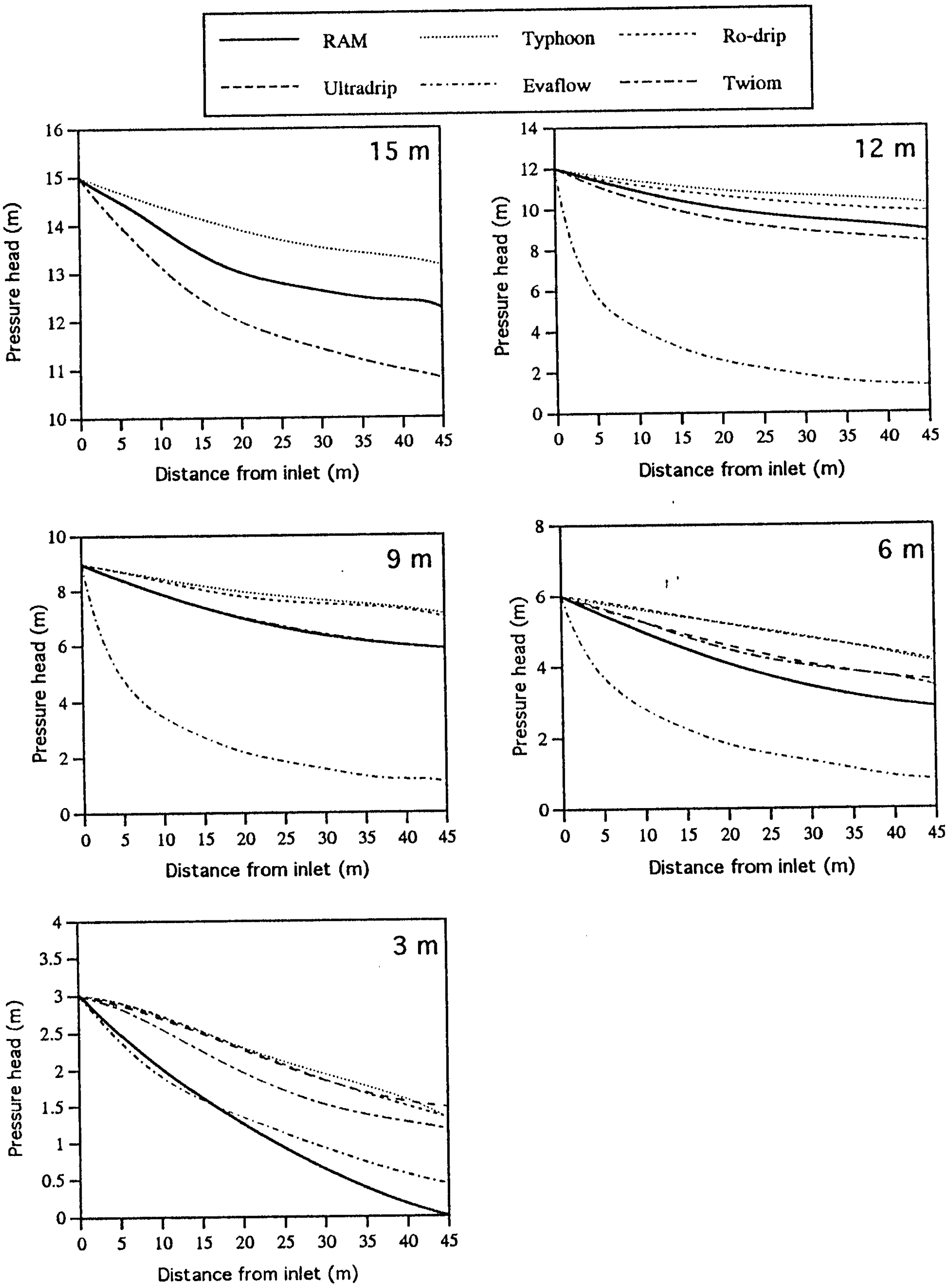


Fig. (5-14): Effect of type of lateral line and inlet pressure head on pressure head distribution at 0 % slope.

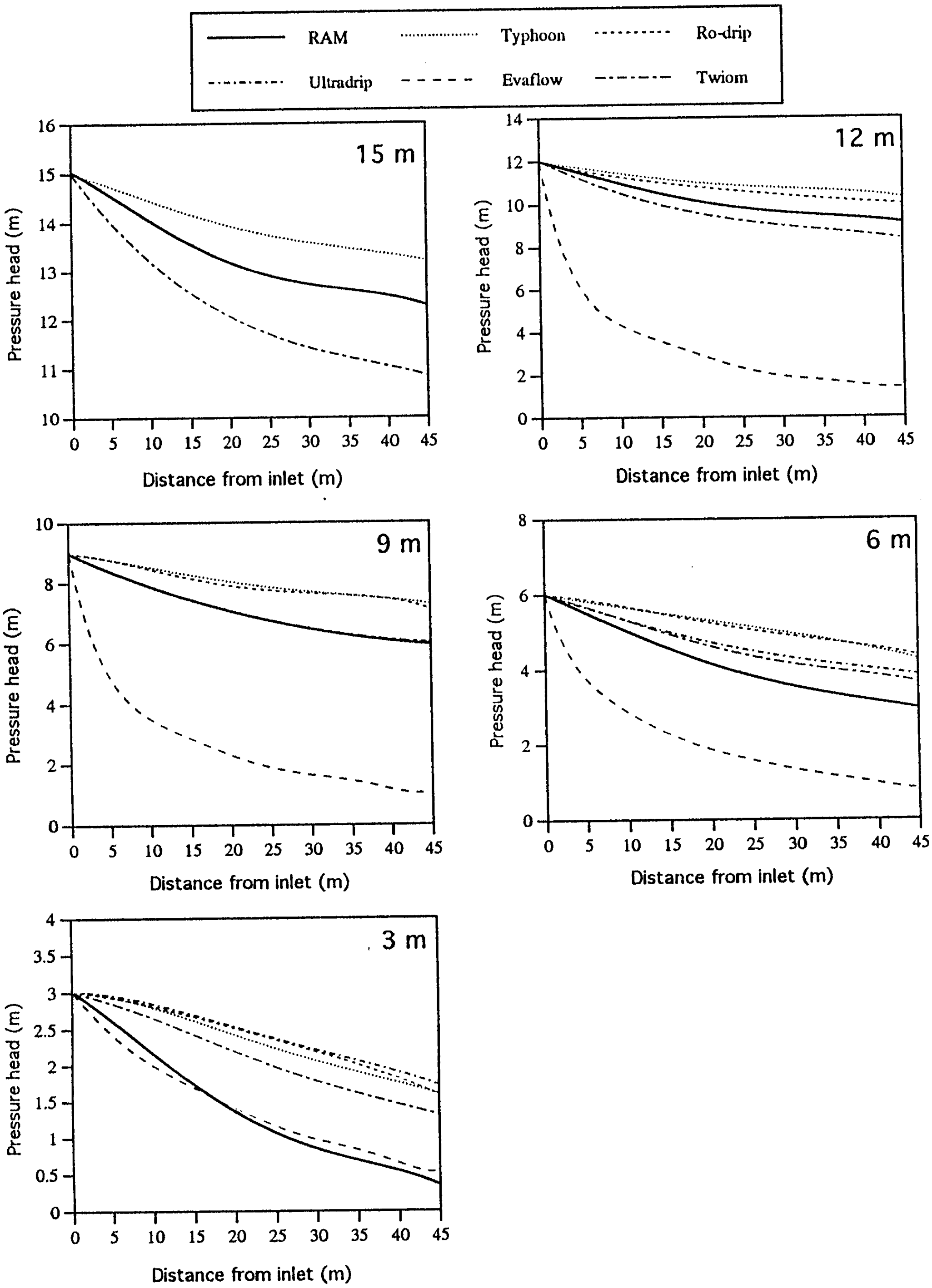


Fig. (5-15): Effect of type of lateral line and inlet pressure head on pressure head distribution at 1 % slope.

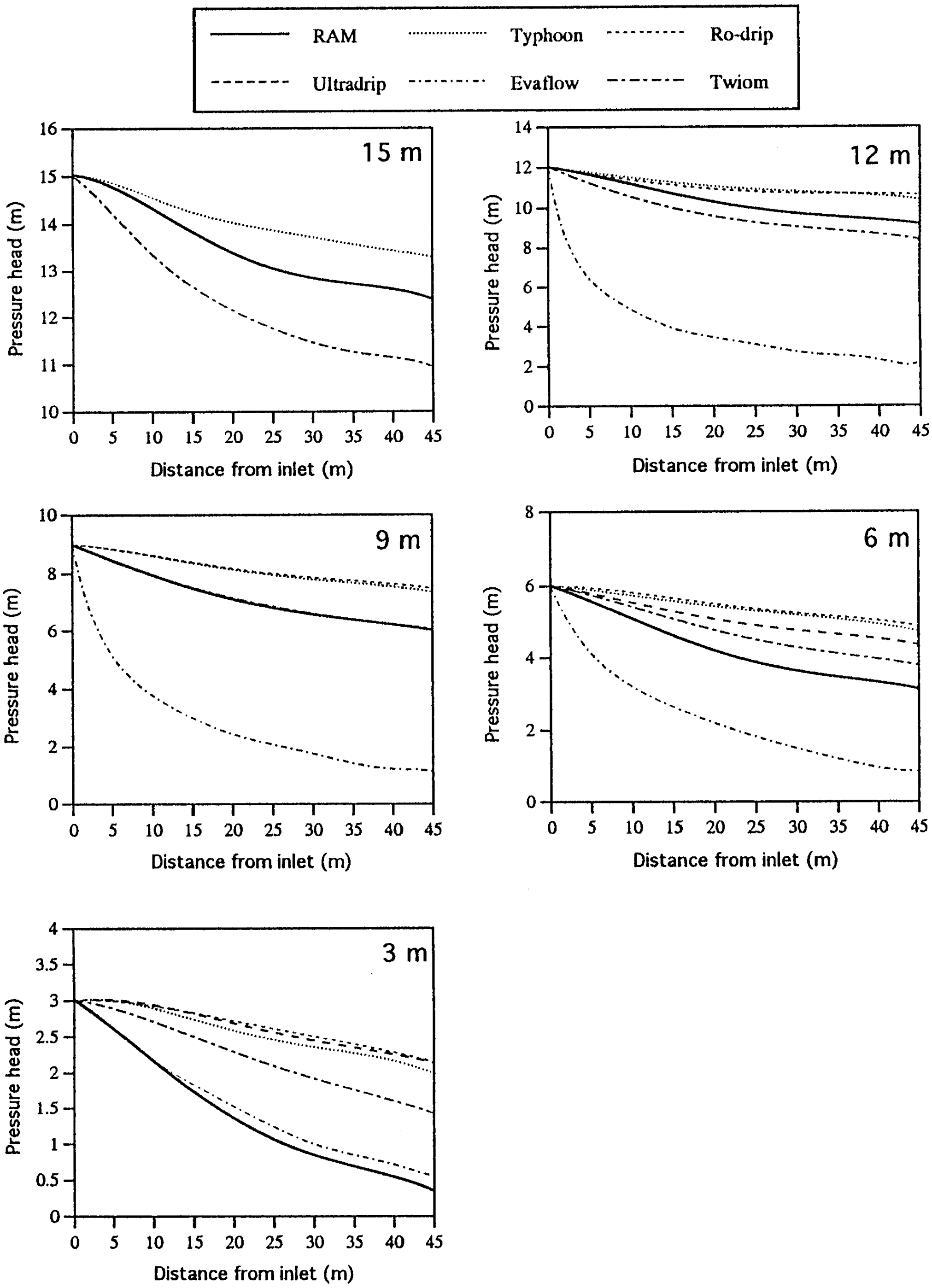


Fig. (5-16): Effect of type of lateral line and inlet pressure head on pressure head distribution at 2 % slope.

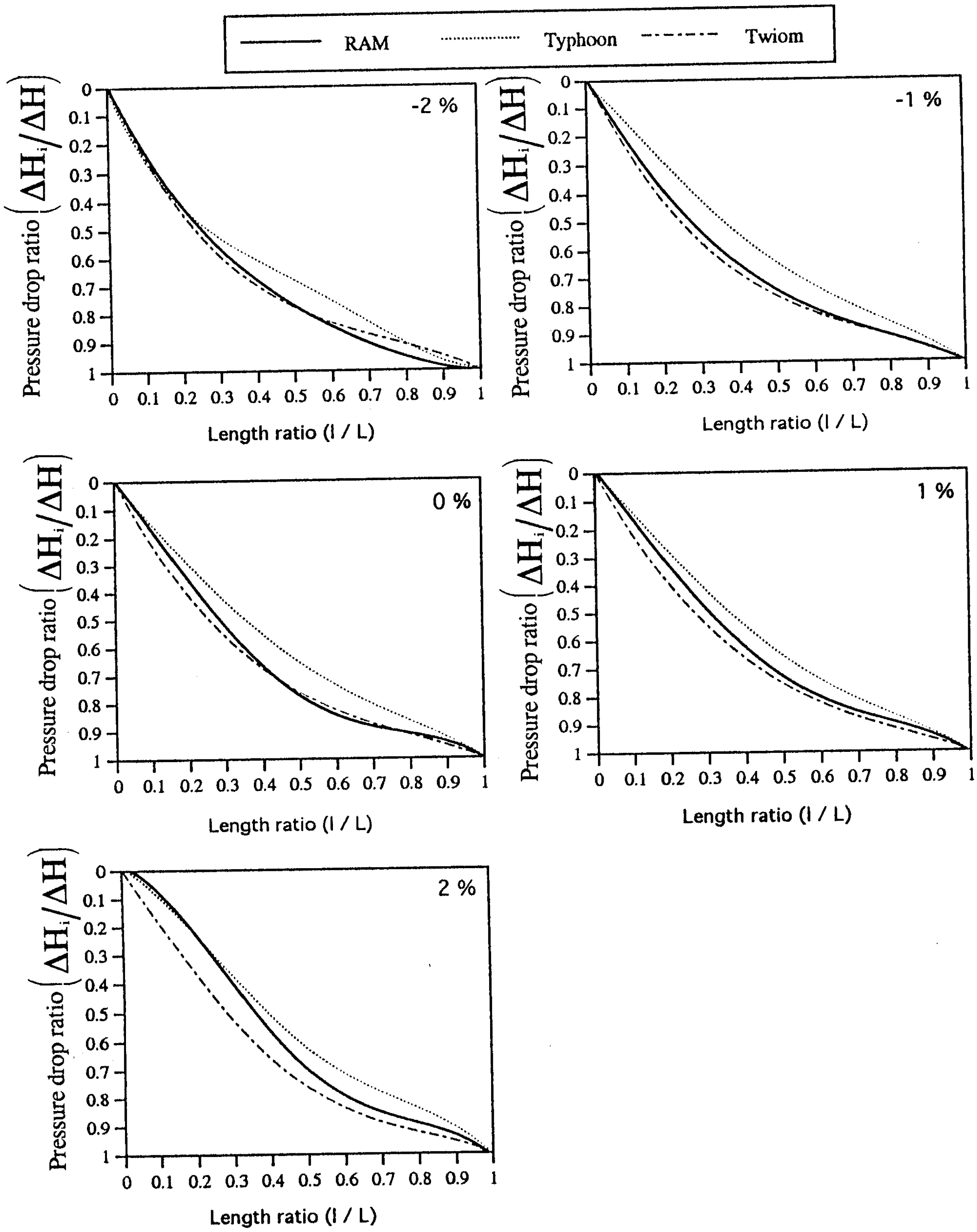


Fig. (5-17): Effect of slope and type of lateral line on pressure drop ratio at 15 m inlet pressure head.

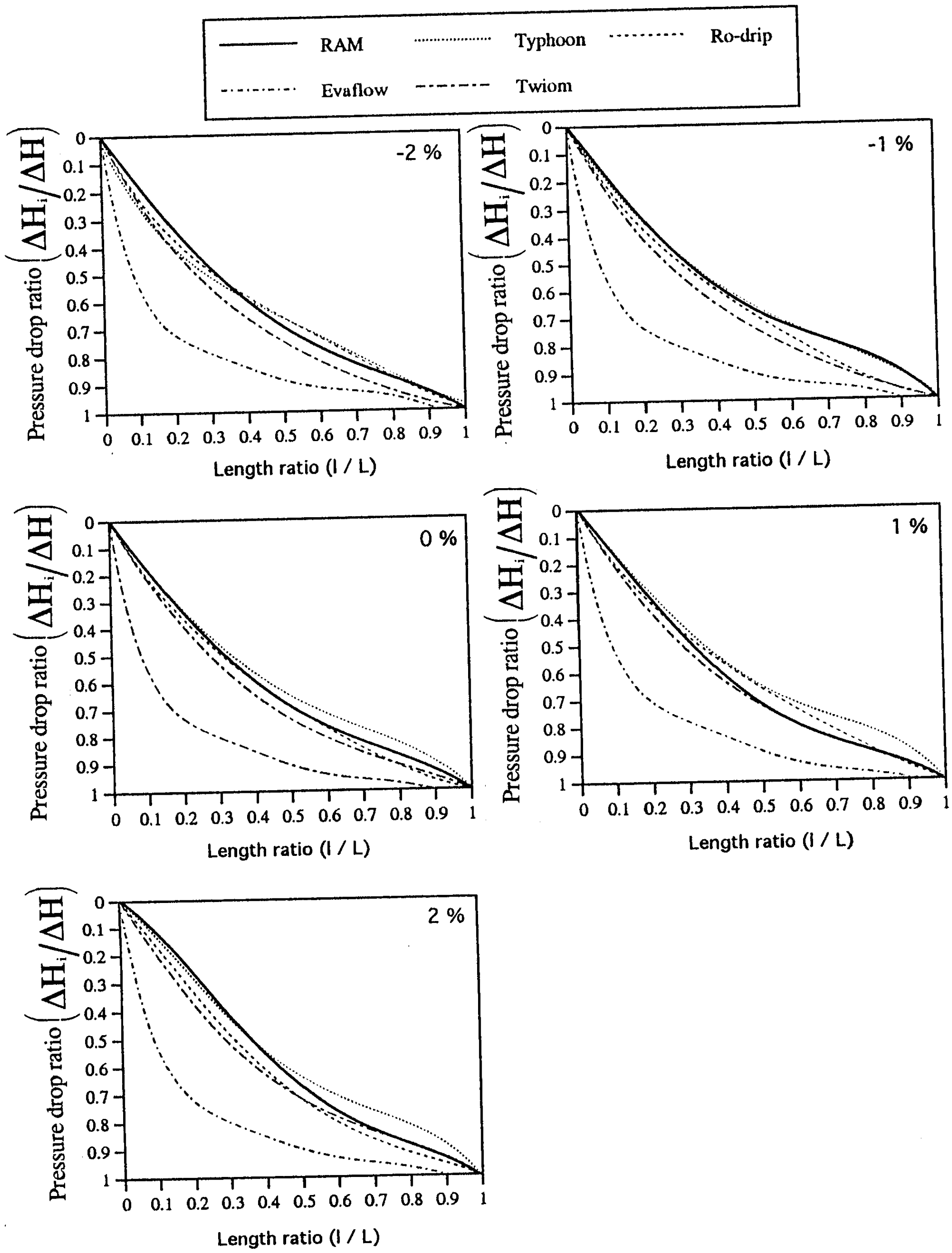


Fig. (5-18): Effect of slope and type of lateral line on pressure drop ratio at 12 m inlet pressure head.

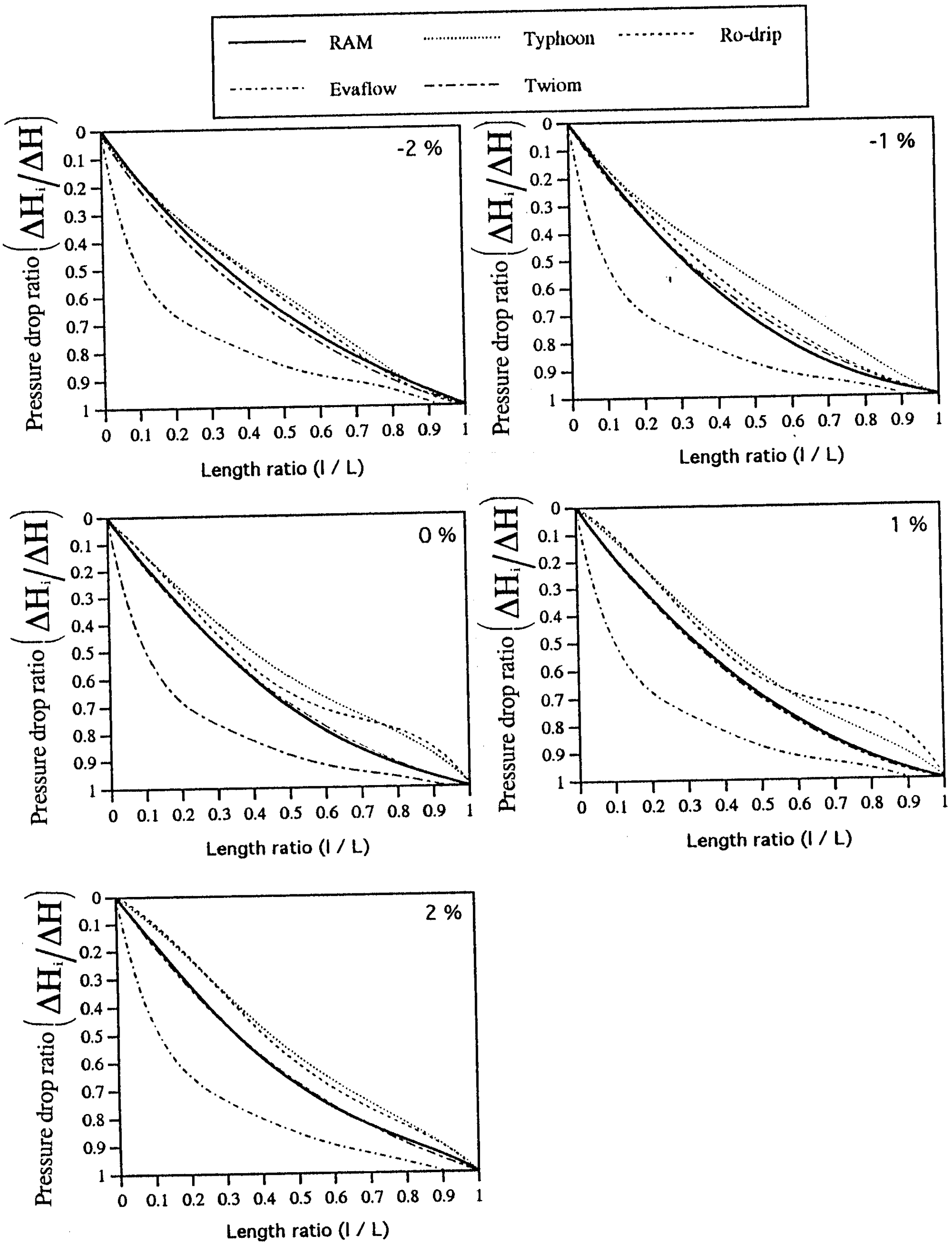


Fig. (5-19): Effect of slope and type of lateral line on pressure drop ratio at 9 m inlet pressure head.

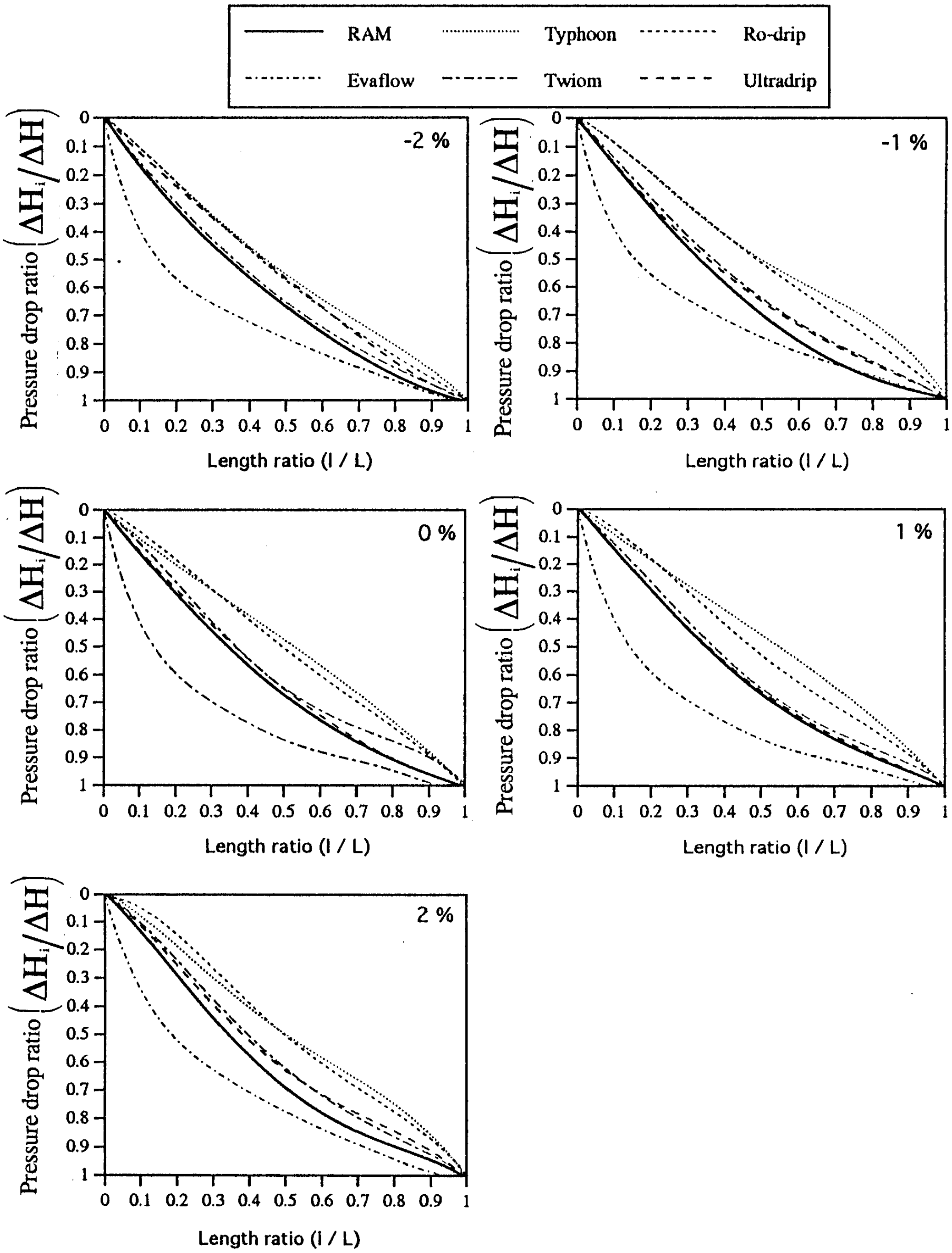


Fig. (5-20): Effect of slope and type of lateral line on pressure drop ratio at 6 m inlet pressure head.

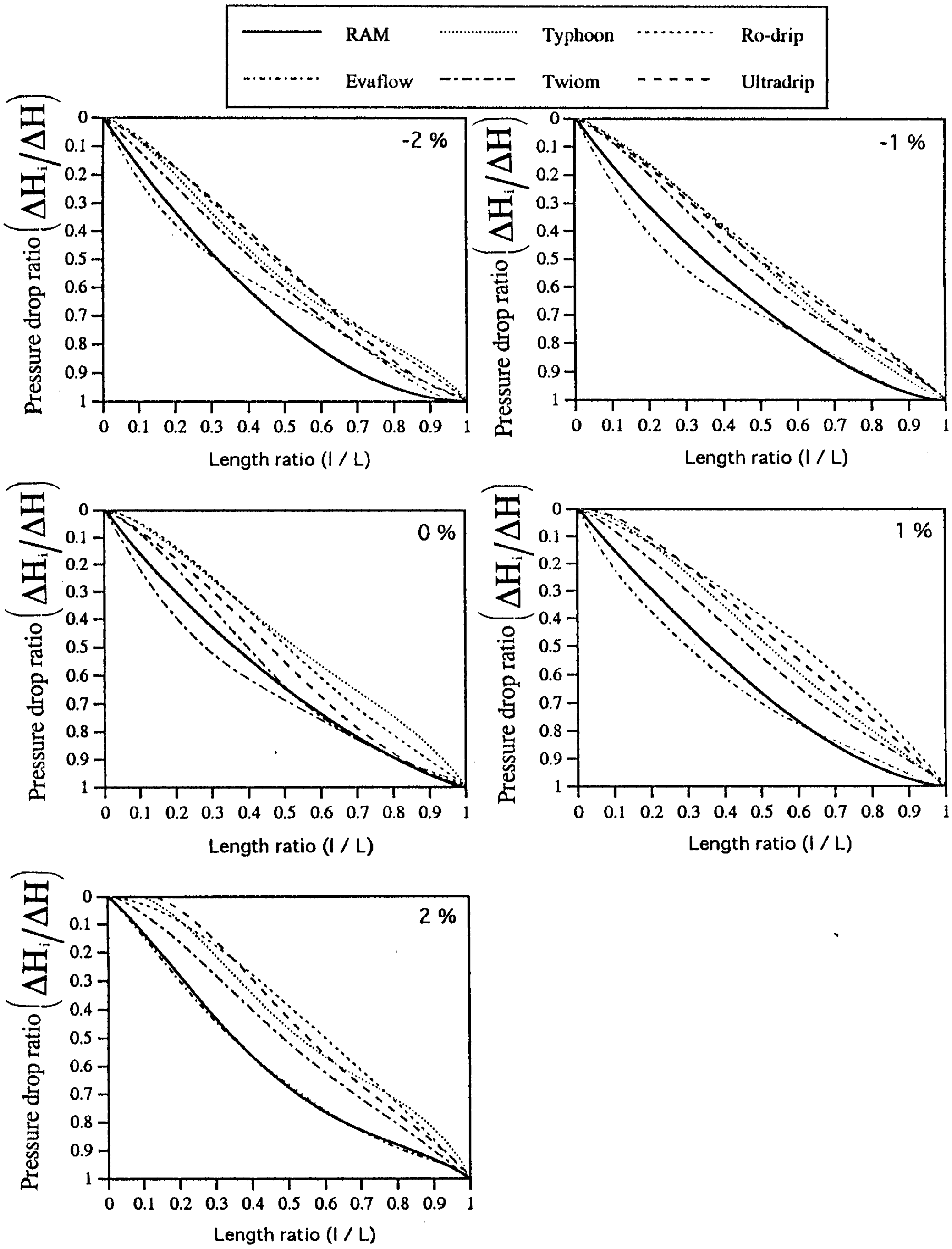


Fig. (5-21): Effect of slope and type of lateral line on pressure drop ratio at 3 m inlet pressure head.

# 6. Summary and Conclusion

Performance of different irrigation equipment
(Design and performance of lateral lines in drip irrigation system)

With a continuous increase of the problem of food shortage in the world and the limited water resources, the irrigation system is increasingly important enough and stable agricultural production.

The main reason for irrigating crops is to supply water from its natural sources, such as rainfall, dew, ground water, and melting snow. Irrigation is needed in areas where water from natural sources is adequate for crop production during only a part of the year or is sufficient for some years and not for others. The amount and timing of irrigation depend on several climatic conditions, soils, and crop factors.

When a reliable and a suitable supply of water becomes available for agriculture, it can result in vast improvements in agricultural production and assure economic returns. Two primary objectives of irrigation in arid areas of the world are:

1) To supply the essential moisture for plant growth, which includes the transport of fundamental nutrients.

2) To leach or dilute salts in the soils.

In addition to the previous objectives, it provides a number of side benefits, such as cooling the soil and the atmosphere to create a more favorable environment for plant growth.

There are a large number of considerations which must be taken into account in the selection of an irrigation system. These factors will vary in importance from location to location and crop to crop. They include the following:-

a) Topography, soil depth, texture, structure, and climate;
b) Crop characteristics;
c) Size and type of water resources, quality of water, depth and quality of ground water;
d) The relative cost of irrigation equipment;
e) Land preparation and labor;
f) The cost of credit;
g) The availability and skill of farm labor.

The purpose of any irrigation system is to convey water from a source to the field and to deliver it to the root zone of the crop. The best irrigation system is one which meets the following factors:-

1) Assurance of maximum economic return to the farmer;

2) Minimal loss of water during conveyance and application;

3) Maintenance of long term productivity of the land through prevention of soil erosion, soil salinization, and rising of the ground water table.

There are two methods of applying irrigation water, namely:-

1) Gravity flow (surface irrigation);

2) Pressurized irrigation (sprinkler - trickle).

Trickle or drip irrigation is one of the latest innovations for applying water, and it represents a definite advancement in irrigation technology. It can be defined as the precise , slow application of water in the form of discrete drops, continuous drops, tiny streams, or miniature sprays through emitters located at selected points along water delivery lines. Water is applied to the soil through emitters at a relatively low operating pressure compared with a sprinkler irrigation system.

There are many advantages for drip irrigation as follows:-

a) Increased beneficial use of available water;

b) Enhanced plant growth and yield;

c) Reduced salinity hazard to plants;

d) Improved fertilizer and other chemical applications;

e) Limited weed growth;

f) Reduced operation labor;

g) Decreasing energy requirements;

h) Controlling the water application;

i) A dry foliage may retard the development of leaf diseases that require humidity and does not necessitate the removal of plant protecting chemicals from the leaves by washing.

The main objective of the present work was to design the optimal lateral lines by studding their performance in a drip irrigation system. The work was carried out in the Arid Land Research Center, Tottori University, Japan. The study includes the following independent factors:-

**1) Type of lateral lines:**

Five different lateral lines were used in the study. Table (7-1) indicates their characteristics:

Table (7-1): Characteristics of different lateral lines.

| Characteristics | Type of lateral lines | | | | | |
|---|---|---|---|---|---|---|
| | RAM | Typhoon | Ro-drip | Ultradrip | Evaflow | Twiom |
| Make | Israel | Israel | U.S.A | Japan | Japan | U.S.A |
| I.D. (mm) | 17.6 | 15.5 | 16.75 | 19 | 21 | 16 |
| Distance between emitters (cm) | 30 | 30 | 20 | 12.5 | 2.5 | 10 |
| Length of lateral line (m) | 45 | 45 | 45 | 45 | 45 | 45 |
| Operating head (m) | 3, 6, 9 12, 15 | 3, 6, 9 12, 15 | 3, 6, 9 12 | 3, 6 | 3, 6, 9 12 | 3, 6, 9 12, 15 |
| Type of lateral | drip emitter | drip emitter | drip tube | drip tube | drip tube | drip tube |

2) Operating head:

The following five operating heads were used in the present study: 3, 6, 9, 12, 15 m respectively at the inlet of lateral lines. They were measured by using a pressure gauge.

3) Slope of lateral lines:

The study included five different slopes. They were -2, -1, 0, 1, 2 % respectively. Wire and bars were used to support and to change the slope of lateral lines and to avoid the occurrence of any deflection.

The following auxiliary equipment was utilized in the present work:

1-An electrical valve: it was used to switch on and off lateral line without changing other valves to prevent any oscillation in lateral line pressure.

2-A flow meter was used to measure the water discharge through lateral the line.

3-A pressure regulator was used to prevent any oscillation in the pressure during operation.

4-A pressure gauge was used to measure the operating pressure.

5-A mercury manometer was used to measure the head every five meters along the lateral line.

6-A calibrated cylinder was used for collecting emitter discharge at a point every five meter along the lateral line.

7-An engineer's leveler and telescopic staff were used to measure the slope of the ground and also for land leveling the ground in a green house . The dimensions of the green house are 8 m x 47 m. There were two big ventilators installed above every door of the green house.

The dependent factors which were studied and were indicated are the following:-

**1. Emitter flow rate-Pressure head relationship:**

Discharge-pressure relationship was calculated from the following equation:-

$$q=kh^c$$

where:-

$k, c$ = Equation constants

$q$ = Emitter flow rate ($cm^3/\text{min}$)

$h$ = Pressur head (m)

New values for $k$ and $c$ were obtained from the present research and indicated as follows:-

| Lateral line | $k$ | $c$ | $R^2$ |
|---|---|---|---|
| RAM | 37.734 | 0.039 | 0.364 |
| Typhoon | 11.832 | 0.442 | 0.980 |
| Ro-drip | 04.850 | 0.819 | 0.967 |
| Ultradrip | 00.346 | 2.768 | 0.984 |
| Evaflow | 04.566 | 1.335 | 0.964 |
| Twiom | 08.392 | 0.487 | 0.996 |

The literatures indicated the value of $c$ constant among 0 to 1. This value depends on type of emitter and flow conditions. Its value equals zero with a pressure compensated emitter, 1.0 with laminar flow, and 0.5 with full turbulent flow.

The result agreed with those in the literatures in case of RAM, Typhoon, Ro-drip, and Twiom but differ with Ultradrip and Evaflow. The differences with Ultradrip and Evaflow were due to the type of these lateral lines. The material of the lateral lines with emitters is plastic that enlarges with high heads. The result showed that manufacturing tolerances could cause relatively large fluctuation in diameter (plastic tube) when the high pressure head was used, especially with the Evaflow and Ultradrip lateral line.

2. Manufacturer's coefficient of variation ($CV$):

Manufacturer's coefficient of variation was calculated from the following equation:-

$$CV = \frac{s}{q'} x100$$

where:-

$s$ = Standard deviation of emitters flow rate

$q'$ = Average emitter flow rate ($cm^3$/min )

The experiments indicated that the manufacturer's coefficient of variation was affected by the operating head and the type of lateral line. The Typhoon lateral line was the best type where $CV$ values for it were 1.93, 1.30, 1.27, 1.70, and 2.02 % for operating heads 3, 6, 9, 12, and 15 m respectively. Evaflow was the worst type while $CV$ values for it were 43.12, 50.10, 38.99, and 52.44 % for operating heads 3, 6, 9, and 12 m respectively.

3. Distribution of emitters discharge along the lateral lines($q_i$):

It was measured by collecting emitters discharge in a calibrated cylinder during a limited time at 5 meter intervals along the lateral lines. The distribution of emitter flow rates along the lateral line was affected by the previous factors as indicated from the experiments. Emitters flow rate increased by increasing both inlet operating pressure head and slope of lateral lines. This result was found in all lateral lines except the RAM when the RAM was equipped with a compensated emitter. The emitters flow rate of the RAM increased significantly by using the head of 6 m compared with 3 m head. Thereafter the emitters flow rate decreased insignificantly by using the following heads: 9, 12, 15 m. The Evaflow was irregular in emitters flow rate. Emitters flow rate was too high at the inlet compared with at the end of this lateral line, especially with at high heads. High regularities in emitters flow rate was found in the Typhoon.

4. Head distribution along the lateral line ($h_i$):

Head distribution in 5 m intervals was measured by using a mercury manometer. It showed a decrease in heads with the distance. This trend was found with all lateral lines. The best result was in the Typhoon and the Evaflow was the worst. The result with the Evaflow was due to the high value of the emitter's flow rate variation.

5. Emitter flow rate variation ($q_{var}$):

Emitter flow rate variation was calculated from the following equation:-

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}}$$

where:-

$q_{max}$ = Maximum emitters flow rate $(cm^3/min)$

$q_{min}$ = Minimum emitters flow rate $(cm^3/min)$

The statistical analysis of emitter flow rate variation indicated a high significant effect by operating head, type and slope of lateral lines. The values of these variations were: 14.37, 14.73, 41.64, 56.05, 95.03, and 14.36 % for the RAM, Typhoon, Ro-drip, Ultradrip, Evaflow, and Twiom respectively. They were: 18.88, 10.09, 10.31, 9.67, and 10.23 % for operating heads of 3, 6, 9, 12, and 15 m respectively. The emitters flow rate variations were: 28.95, 27.57, 28.23, 27.66, and 30.60 % for lateral line's slope -2, -1, 0, 1, and 2 % respectively. The results indicated that the best operating conditions that give the lowest emitter flow rate variations were with the Typhoon lateral line at 15 m head and 2 % slope as shown in (Table 4-15). The worst lateral lines with these variations were the Evaflow and Ultradrip at 3 m head and -2% slope.

6. Head variation ($h_{var}$):

The head variations along the lateral line was calculated from the following equation:-

$$h_{var} = \frac{h_{max} - h_{min}}{h_{max}}$$

where:-

$h_{max}$ = Maximum head (m)

$h_{min}$ =Minimum head (m)

The above mentioned independent factors had a highly significant effect on the head variation. The head variations were 75.12, 43.17, 41.54, 45.83, 88.29, and 54.86 % for RAM, Typhoon, Ro-drip, Ultradrip, Evaflow, and Twiom respectively. A decreasing both operating head and slope of lateral line increased the head variations. The percentages of head variations were 72.87, 42.56, 30.68, 23.63, and 19.83 for operating heads 3, 6, 9, 12, 15 m respectively. They were 56.09, 53.09, 48.14, 45.16, and 40.18 % for slope -2, -1, 0 , 1, 2 % respectively. The best result was obtained from the Typhoon at 15 m operating head and 2 % slope. The RAM was the worst lateral line during operation under 3 m head and -2 % slope. As the variations of emitters flow rate increased the variation of heads increased.

7. Distribution of uniformity ($DU$):

The distribution of uniformity is a useful indicator of distribution problems. A low ($DU$) indicates that excessive deep percolation losses will occur if adequate irrigation is supplied to all areas. The following equation used to calculate ($DU$):

$$DU = \frac{q'_l}{q'} x100$$

where:-

$q'_l$ = Average low quarter depth of water in filtrated ($cm^3/\min$)

The statistical analysis proved that the $DU$ was significantly affected by all independent factors. It increased by increasing both operating head and slope of lateral line. It increased by the following ratios: 4.16, 4.28, 4.06, and 4.30 for operating heads 15, 12, 9, and 6 m respectively compared with 3 m operating head of $DU$ equals 92.27 %.

The increasing ratios of $DU$ were 4.49, 8.19, 8.97, and 9.31 for slopes -1, 0, 1, 2% respectively compared with -2 % slope where its value was 79.08%. Also, $DU$ values were 93.94, 93.91, 82.79, 73.43, 24.57, and 94.92 % for the following lateral lines: RAM, Typhoon, Ro-drip, Ultradrip, Evaflow , and Twiom respectively. The highest water loss value was in the Evaflow lateral line at 12 m operating pressure head. Typhoon and Twiom gave the lowest values for water losses.

8. Head loss ($\Delta H$):

The maximum pressure head difference along the lateral line is called pressure head loss. The present study showed that the independent factors had a highly significant effect on head loss. The head loss increased by decreasing the slope of the lateral lines and increasing the operating head. The lowest loss in head was 0.85 m for the Ro-drip at 3 m operating head and 2 % slope. The highest head loss was 11.23 m for the Evaflow at 12 m operating head and -2 % slope because emitter flow rate decreased significantly during the first 1/4 of the lateral line

9. Coefficient of uniformity ($UC$):

Coefficient of uniformity was calculated from the following equation:-

$$UC = (1 - \frac{\Sigma |q - q'|}{nq'}) x 100$$

where:-

$n$ = Number of observed emitters

The statistical analysis indicated that the independent variables had a highly significant effect on the coefficient of uniformity. The Typhoon was the best lateral line while $UC$ value for it was 99.43 % at 15 m of operating head and 2 % slope. The lowest coefficient of uniformity was 0 % with the Evaflow lateral line at 12 m of operating head and -2 % slope. From the obtained results the lateral lines could be arranged as follows: Twiom, Typhoon, RAM, Ro-drip, Ultradrip, and Evaflow whereas $UC$ values for them were 96.11, 96.00, 95.12, 88.78, 76.48, and 23.35 % respectively.

## Conclusion

The design and performance of lateral lines in drip irrigation system are presented in this work. The experimental results for discharge-pressure were agreement to those obtained by other researchers in case of RAM, Typhoon, Ro-drip and Twiom but differed in case of Ultradrip and Evaflow. The manufacturer's coefficient of variation that caused by nonuniform production from manufacturer was affected on both emitter flow rate and pressure head distribution along the lateral line. The effect of type and slope of lateral line and operating pressure head on emitter flow rate variation, pressure head variation, distribution of uniformity, pressure head losses and coefficient of uniformity are summarized as followis:

| Factors | | Flow rate variation (%) | Pressure variation (%) | Distribution of uniformity (%) | Pressure head losses (m) | Coefficient of uniformity (%) |
|---|---|---|---|---|---|---|
| Lateral line | RAM | 14.37 | 75.12 | 93.94 | 3.07 | 95.12 |
| | Typhoon | 14.73 | 43.17 | 93.91 | 1.76 | 96.00 |
| | Ro-drip | 41.64 | 41.54 | 82.79 | 1.68 | 88.78 |
| | Ultradrip | 56.05 | 45.83 | 73.43 | 1.96 | 76.48 |
| | Evaflow | 95.03 | 88.29 | 24.57 | 3.99 | 23.35 |
| | Twiom | 14.36 | 54.86 | 94.92 | 2.29 | 96.11 |
| Inlet pressure head (m) | 15 | 10.23 | 19.83 | 96.10 | 2.98 | 97.31 |
| | 12 | 9.67 | 23.63 | 96.22 | 2.84 | 97.47 |
| | 9 | 10.31 | 30.68 | 96.01 | 2.76 | 97.34 |
| | 6 | 10.09 | 42.56 | 96.24 | 2.55 | 97.41 |
| | 3 | 18.88 | 72.87 | 92.27 | 2.19 | 94.08 |
| Slope of lateral line (%) | -2 | 35.91 | 56.09 | 79.09 | 3.17 | 80.77 |
| | -1 | 30.04 | 53.09 | 82.74 | 3.00 | 83.69 |
| | 0 | 28.23 | 48.14 | 84.58 | 2.77 | 85.44 |
| | 1 | 25.18 | 44.82 | 86.17 | 2.62 | 86.90 |
| | 2 | 23.64 | 40.17 | 86.44 | 2.40 | 87.15 |

## 7. References

Abd El-Slam M. (1985). "Engineering studies of the irrigation systems for potato crop". M. Sc. thesis, Mansoura University, EGYPT.

Amir I., E.Gofman, S.Pleban, D.Nir and M.Rodeh (1980), "Computerized scheduling of complex irrigation systems". TRANSACTION of ASAE. 23(6):1413-1418,1423.

Amir I. and V. Alchanatis (1992). " Procedure for predicting and designing moving sprinkler application patterns". Irrig. Sci.13(2):93-98.

Amir I. and J. Dag (1993). " Lateral and longitudinal wetting patterns of very low energy moving emitters ". Irrig. Sci. 13(4):183-187.

Anon (1978). "Describing Irrigation Efficiency and Uniformity". Journal of Irrigation and Drainage Division. 104(IR1):35-41.

ASAE, (1988). " Field evaluation of microirrigation systems". ASAE Engineering Practice. ASAE EP458.

ASAE, (1991). "Design and installation of microirrigation systems". ASAE Engineering Practice: ASAE. EP 405.1

Bader A. E. (1980). " Evaluation of drip irrigation system under Egyptian conditions". ph. D. thesis , Cairo University, EGYPT.

Bader A. El-Amin (1987). "Soil moisture distribution and fruit yield in an orange orchard irrigated by drip and mini-sprinkler systems". Misr J. Ag. Eng., 4(4):313-332.

Bresler E., and Rokuro Y. (1990). "Drip Irrigation Technology in Semi-Arid Regions and International Cooperation". Journal of Irrigation Engineering and Rural Planning. The Japanese Society of Irrigation, Drainage and Reclamation Engineering (JSIDRE), No. 19: 48-62.

Bucks D.A., L.J.Erie, O.F.French, F.S.Nakayama and W.D.Pew (1981). "Subsurface trickle irrigation management with multiple cropping". Transactions of ASAE. 24(6):1482-1489.

Chaudhry F. H. (1978). "Nonuniform sprinkler irrigation application efficiency". Journal of Irrigation and Drainage Division, 104(IR2):165-178.

Christiansen J.E. (1942). "Irrigatin by sprinklers." Bull. 670. Univ. of California. Berkeley, Calif.

Clemmens A. J., (1987). " A statistical analysis of trickle irrigation uniformity". TRANSACTION of the ASAE 30(1):169-175.

Dasberg S., and Eshel B. (1985). "Drip irrigation manual". International Irrigation Information Center (IIIC). P.O.B. 49, Volcani Center, 50250 Bet Dagan, Israel.

Edmar J. Scaloppi and Richard G. Allen, (1993); "Hydraulics of irrigation laterals: Comparative analysis". Journal of Irrigation and drainage Engineering. 119(1):91-115.

Eduardo A.H., M.A.Marino and J.Chavez-Morales (1985). "Procedure to select an optimum irrigation method ". Journal of Irrigation and Drainage Engineering. ASCE 111(4 ):319-329.

Eduardo A.H., M.A.Marino and J.Chavez-Morales (1986). " Surface irrigation optimization models". Journal of Irrigation and Drainage Engineering ASACE 112(1):1-19.

El-berry A.M., M.H. Afifi and A.H. Ahmed (1989). "Effects of irrigation system on moisture pattern, productivity and harvesting operation of fodder in Arid Lands". Misr J. Ag. Eng., 6 (4) : 359-37.

Gomes K.A. and A.G. Arturo (1984). "Statistical procedures for agriculture research" Second Edition. JOHN WILEY & SONS, Inc. 605 Third Avenue, New York, New Tork 10158.

Harry J.B. and A.M.Soom (1981). "Trickle irrigation lateral design on sloping field". Transactions of the ASAE. 24 (4):941-944,950.

Hassan (1987a). "Optimization of drip irrigation design". Misr J. Ag. Eng. 4 (4):377-392.

Hassan (1987b). "Effect of dripper discharge rate on distribution of moisture in sandy soils under drip irrigation system". Misr J. Ag. Eng. 4 (4):393-405.

Hassan, M.H. and Younis, S.M. (1987). "Pipe selection in relation to energy consumption under drip irrigation system". Misr J. Ag. Eng., 4 (2):175-201.

Hathoot, H.M., and A.I. Al-Amoud and F.S. Mohammed; (1993) "Analysis and design of trickle-irrigation laterals". Journal of Irrigation and Drainage Engineering. 119(5):756-767.

Hathoot H. M., H.M.Abo-Ghobar, A.I.Al-Amoud and F.S.Mohammad (1994). "Analysis and design of sprinkler irrigation laterals". Journal of Irrigation and Drainage Engineering. 120(3):534-549.

Hernandez J.J.M., B.Bar-Yosef and U.Kafkafi (1991). "Effect of surface and subsurface drip fertigation on sweet corn rooting, uptake, dry matter production and yield". Irrig. Sci.12(3):153-159.

Hill R.W. and Jack Keller (1980). "Irrigation system selection for maximum crop profit". Transactions of the ASAE 23(2):366-372.

Hillel D. (1982). "Advances in irrigation". Principles, practices, and potentialities of trickle (drip) irrigation. volume 1, New York, London.

Hillel D. (1983). "Advances in irrigation". volume 2, New York, London.

Hillel D. (1987). "The efficient use of water in irrigation". Principles and Practices for Improving Irrigation in Arid and Semiarid Regions. World Bank Technical Paper Number 64. The World Bank, Washington, D.C.

James R.G. and Darrel G. Watts (1977), "Possible Energy savings in Irrigation". Journal of the Irrigation and Drainage Division. ASCE, 103(IR4):445-457.

Jam L. G., (1988). "Principles of farm irrigation system design". 605 Third Avenue, New York, New York 10158.

Keller J. and Karmeli D. (1974). "Trickle Irrigation Design Parameters". Transactions of the ASAE. 17(4):678-784.

Keller J. and Karmeli D. (June,1974). "Trickle irrigation design". Rain Bird Sprinkler Manufacturing Co., Glendora, calif.

Keller J. and Ron D. Bliesner (1990). "Sprinkle and Trickle irrigation" Van Nostrand Reinhold. 115 fifth Avenue, New York, New York 10003.

Kyung H. Y. and J. R. Busch (1985). " Least-cost planning of irrigation systems". Journal of Irrigation and Drainage Engineering. ASCE 111(4):352-368.

Letey J. (1985). "Irrigation uniformity as related to optimum crop production-additional research is needed". Irrig. Sci. 6(4): 253-263.

Letey J., A.Dinar, C.Woodring and J.D. Oster (1990) " An economic analysis of irrigation systems". Irrig. Sci. 11(1):37-43.

Nakayama F. S., R. G. Gilbert and D. A. Bucks, (1978). "Water treatments in trickle irrigation system". Journal of Irrigation and Drainage Division. 104(IR1):23-34.

Nishiyama S., M.Kuroda, H.Kawano, T.Yano and I.P.Wu (1993); " A simple micro irrigation design for small farms in Japan" Proceedings of the workshop on micro irrigation worldwide. Thursday, Sept. 2, The Hague, The Netherlands.

Plaut Z., M. Ben-Hur and A. Meiri (1992). "Yield and vegetative growth as related to plant water potential of cotton irrigated with a moving sprinkler system at different frequencies and wetting depths". Irrig. Sci. 13(1):39-44.

Richard G.A. (1986). "Sprinkler irrigation project design with production functions". Journal of Irrigation and Drainage Engineering. ASCE 112(4):305-321.

Roland P. P.(1977). "Design of irrigation pipe laterals with multiple outlets". Journal of irrigation and drainage division. 103(IR2):179-195.

Schwartzman M. and B. Zur (1986). "Emitter spacing and geometry of wetted soil volume". Journal of Irrigation and Drainage Engineering, ASCE. 112(3):242-253.

Solomon K. and J. Keller (1978). "Trickle irrigation uniformity and efficiency". Journal of Irrigation and Drainage Division. 104(IR3): 293-306.

Terry A. H. and F.A. Barinas (1980) " Pressure losses across trickle irrigation fittings and emitters" TRANSACTION of ASAE. 23(4):928-933.

Walker W. (1987). "Surface irrigation theory and practice". PRENTICE-HALL, INC., Englewood Cliffs, New Jersey 07632.

Warrick A. W. and M. Yitayew (1988). "Trickle Lateral Hydraulics. I: Analytical Solution". Journal of Irrigation and Drainage Engineering. 114(2): 281-287.

Wu I.P. and H.M. Gitlin; (1975) "Energy gradient line for drip irrigation lateral". Journal of the irrigation and drainage division. 101(IR4):322-326.

Wu I.P. and H.M. Gitlin (1977). "Design of drip irrigation lines with varying pipe sizes". Journal o the irrigation and drainage division. Technical Notes Proc. Paper 13384. 103(IR4):499-503.

Wu I.P. and H.M. Gitlin, (1979):" Drip irrigation design on nonuniform slopes". Journal of the irrigation and drainage division, 105(IR3):289-303

Wu I.P. and H.M. Gitlin (1981). "Preliminary concept of a drip irrigation network design". TRANSACTION of the ASAE. 24(2):330-334,339.

Wu I.P. (1983), "Design of drip irrigation lateral length on uniform slopes". Irrig. Sci. 4 (2):117-135.

Wu I.P. and H.M. Gitlin, (1983) " Drip Irrigation Application Efficiency and Schedules" , TRANSACTIONS of the ASAE 26(1):92-99

Wu I.P. and J.M. Irudayaraj (1987)"Evaluation of uniformity parameters for drip irrigation design". ASAE paper No 87-2522

Wu I.P. (1988). "Efficient water management using deficit concept on sprinkler irrigation". 6th Congress. Asian and Pacific Division. International Association for Hydraulic Research. Kyoto, Japan. 20-22, July.

Wu I.P. (1992a). " Energy gradient line for direct hydraulic calculation in drip irrigation design". Irrig. Sci.13(1): 21-29

Wu I.P. (1992b). " A simple graphic solution for drip lateral design". International conference of Agricultural Engineering. Paper No, 9209 103.

Yaron B., E. Danfors and Y. Vaadia (1973). " Arid Zone Irrigation". Berlin-Heidelberg-New York Springer-Verlag / ISBN 3-540-06206-8.

Yitayew M. and A. W. Warrick (1987). "Velocity head considerations for trickle laterals". Journal of Irrigation and Drainage Engineering. 113(4):611-615.

Yitayew M. and A. W. Warrick (1988). " Trickle Lateral Hydraulics. II : Design and Examples". Journal of Irrigation and Drainage Engineering, 114(2):289-300.

# ARABIC SUMMARY

بسم الله الرحمن الرحيم

## أداء معدات الري المختلفة
## (تصميم وأداء الخطوط الفرعية في نظام الري بالتنقيط)

مع الزيادة المطردة في عدد السكان ونقص الموارد الغذائية مع ثبات المصادر المائية أصبح نظام الري غاية في الأهمية لامكانية زيادة الرقعة المنزرعة وكذلك الأنتاج الزراعي.

وحيث أن الهدف الاساسي من ري المحاصيل هو إضافة الماء من مصادرها الطبيعية المتاحة مثل الامطار والندي وسريان المياه الجوفية.........الخ وذلك إلي منطقة الجذور ولما كانت هذه المصادر محدودة حيث أنها تكفي لتغطية الأحتياجات المائية لجزء فقط من العام لأن هذه الاحتياجات تعتمد علي العوامل المناخية والتربة والمحصول المنزرع. وعندما تتم إضافة المياه بالكمية المطلوبة للنبات في الوقت المناسب ينعكس ذلك علي الإنتاج الزراعي مما يترتب عليه زيادة الدخل وعليه يتحسن الاقتصاد القومي. والري في المناطق الجافة يقوم علي ثلاثة دعائم أساسية هي علي النحو التالي :

١-غسيل الاملاح الموجودة بالتربة.

٢-خلق مناخ مناسب لإنبات البذور.

٣-اضافة المياه للتربة والذي من خلاله تنتقل العناصر الغذائية اللازمة للنبات.

وهناك العديد من العوامل التي تؤخذ في الاعتبار عند اختيار نظام الري. وهذه الاعتبارات تختلف في أهميتها من منطقة إلي أخري ومن محصول إلي أخر وتتلخص هذه العوامل فيما يلي:

١-طبوغرافية التربة.

٢-نوع وبناء التربة.

٣- المناخ.

٤- خواص ونوع المحصول.

٥- نوع وكمية المياه المتاحة.

٦-عمق المياه الجوفية.

٧-مهارة العمالة وتوافرها.

٨-تكاليف نظم الري.

والهدف الاساسي من أي نظام للري هو نقل الماء من مصادره المختلفة إلي الحقل وكذلك توزيعها داخل الحقل إلي منطقة جذور النباتات. ويكون أحسن النظم هو الذي يحقق العوامل الثلاثة التالية:

١-تحقيق أقصي عائد للمزارع.

٢-أقل فقد في المياه أثناء نقلها إلي الحقل.

٣- حفظ وصيانة التربة من الاضرار الناتجة من نحر وتأكل التربة بالجريان السطحي - التمليح - إرتفاع منسوب المياه الجوفية.

وتقسم نظم الري إلي نوعين رئيسيين هما:

١-الري بإستخدام الجاذبية الارضية ( الري السطحي ).

٢-الري بإستخدام الضغط ( الري بالرش - الري بالتنقيط ).

ويعتبر الري بالتنقيط من نظم الري الحديث والذي يقوم علي إضافة كميات صغيرة من الماء من خلال فتحة صغيرة تسمي بالنقاط داخل أنبوبة بلاستيك تسمي بالخطوط الفرعية والتي توضع علي سطح التربة بإستعمال ضغوط تشغيل منخفضة مقارنة بنظم الري بالرش. ويتميز الري بالتنقيط بالاتي:

١-زيادة كفاءة إستعمال الماء.
٢-تحسين نمو النبات والمحصول.
٣-تقليل الاضرار الناتجة من التمليح.
٤-إضافة السماد والمواد الكميائية مع ماء الري.
٥-تقليا نمو الحشائش.
٦-تقليل العمالة.
٧-تقليل الطاقة المستعملة في الري.
٨-التحكم في كمية المياه المضافة للتربة.
٩-المحافظة علي جفاف أوراق النبات مقارنة بالري بالرش مما يقلل الإصابة بالامراض والفطريات.

***الهدف من إجراء البحث***

أجري هذا البحث بهدف تصميم ودراسة أداء الخطوط الفرعية الموجودة في نظام الري بالتنقيط . وقد أجري هذا البحث بمركزبحوث الأراضي القاحلة التابع لجامعة توتوري باليابان.

***وأشتملت الدراسة علي العوامل المستقلة التالية:***

١-نوع الخطوط الفرعية:

تم إستخدام ستة أنواع مختلفة من حيث الاقطار وجهة الصنع وهي مبينة في الجدول علي النحو التالي:

| الخواص | أنواع الخطوط الفرعية | | | | | |
|---|---|---|---|---|---|---|
| | RAM | Typhoon | Ro-drip | Ultradrip | Evaflow | Twiom |
| بلد الصنع | اسرائيل | اسرائيل | أمريكا | اليابان | اليابان | أمريكا |
| القطر (مم) | ١٧٫٦ | ١٥٫٥ | ١٦٫٧٥ | ١٩ | ٢١ | ١٦ |
| المسافة بين النقاطات (سم) | ٣٠ | ٣٠ | ٣٠ | ١٢٫٥ | ٢٫٥ | ١٠ |
| طول الخط (متر) | ٤٥ | ٤٥ | ٤٥ | ٤٥ | ٤٥ | ٤٥ |
| ضاغط التشغيل (متر) | ٣،٦،٩ ١٢،١٥ | ٣،٦،٩ ١٢،١٥ | ٣،٦،٩ ١٢ | ٣،٦ | ٣،٦،٩ ١٢ | ٣،٦،٩ ١٢،١٥ |

٢-ضاغط التشغيل:

تم أستخدام خمسة ضواغط تشغيل مختلفة هي ٣، ٦، ٩، ١٢، ١٥ متر عند بداية الخطوط الفرعية وكانت تقاس بإستخدام مقياس ضغط Pressure gauage تدريجه من صفر إلي ٢كجم/سم٢.

**٣-ميول الخطوط الفرعية:**

تم إستخدام خمسة ميول مختلفة هي -٢ ، -١ ، صفر ، ١ ، ٢ ٪ وتم الاستعانة بسلك wire ودعامات تثبيت barsللتحكم في تغيير ميول الخطوط الفرعية وكذلك منع إرتخائها عند التشغيل.

***الادوات المستخدمة في البحث:***

١-صمام كهربائي Electrical valve: وكان يستعمل في فتح وغلق الخط دون الحاجة إلي تغيير الصمامات الاخري حتي لا يحدث أي تغيير في الضغط الداخلي للخطوط الفرعية.

٢-مقياس التصرف Flow-meter: وكان يستخدم في حساب كمية المياه المنصرفة عبر الخطوط الفرعية.

٣-منظم الضغط Pressure regulator وكان يستخدم في منع تذبذب الضغط أثناء التشغيل.

٤-مقياس الضغط Pressure gauge تم إستخدامه في قياس ضغط التشغيل تحت الدراسة.

٥-مانومتر زئبقي Hg manometer أستخدم في قياس الضاغط كل خمسة أمتار علي طول الخطوط الفرعية.

٦-مخبار مدرج Calibrate cylinder أستخدم في تجميع وحساب التصرف الخارج من النقاطات كا خمسة أمتار من بداية الخطوط الفرعية كل علي حده.

٧-ميزان مساح Engineer's levelerوقامة تليسكوبية Telescopic staff: تم إستخدامهم في قياس ميل الارض الطبيعية وفي عملية التسوية داخل صوبة زراعية مقياسها ٧ ×٤٧ متر.

٨- شفاطات ventilators تم التحكم في درجة الحرارة داخل الصوبة عن طريق عدد إثنان من الشفاطات ذات أقطار كبيرة مثبتة في بداية ونهاية الصوبة في الجزء الذي يعلو الباب الامامي والخلفي للصوبة.

***أهم النتائج التي تم التوصل إليها:***

كانت العوامل التابعة والتي تم دراستها وأهم النتائج التي تم التوصل إليها هي علي النحو التالي:

١-العلاقة بين تصرف النقاط والضاغط عند النقاط ( $q-h$ ): تم حساب هذه العلاقة بإستخدام المعادلة التالية:-

$$q=kh^{c}$$

حيث أن :- $k,c$= ثوابت المعادلة

$q$=تصرف النقاط (سم٣/دقيقة)

$h$= الضاغط عند النقاط (متر)

ومن المراجع السابقة نجد أن قيمة الثابت $c$ تنحصر بين صفر والواحد الصحيح وهذا يعتمد علي نوع السريان وكذلك علي نوع النقاط نفسه حيث أنها تكون صفر مع النقاط المزود بمنظم للضغط وكذلك تكون ٥ر. في السريان المضطرب بينما تأخذ قيمة الواحد الصحيح عندما يكون السريان خطي.

وقد وجد من التجارب التي أجريت في هذه الدراسة أن قيم هذه الثوابت ( $k,c$ ) علي النحو التالي:-

| | $k$ | $c$ |
|---|---|---|
| RAM | ٣٧٫٧٣٤ | ٠٫٠٣٩ |
| TYPHOON | ١١٫٨٣٢ | ٠٫٤٤٧ |
| Ro-drip | ٤٫٨٥٠ | ٠٫٨١٩ |
| Ultradrip | ٠٫٣٤٦ | ٢٫٧٦٨ |
| Evaflow | ٤٫٥٦٦ | ١٫٣٣٥ |
| Twiom | ٨٫٣٩٢ | ٠٫٤٨٧ |

وبذلك تتفق النتائج المتحصل عليها من التجارب مع نتائج الأبحاث السابقة للخطوط الفرعية لكل من RAM , Typhoon , Ro-drip , Twiom بينما كانت تختلف مع الخطوط الفرعية التالية Ultradrip , Evaflow ويعزي هذا إلي أن هذه الخطوط الفرعية عبارة عن أنابيب من البلاستيك وعندما يزداد ضاغط التشغيل يحدث تمدد لجدران الخط وكذلك للنقاطات مما يزيد من تصرفها بصورة عالية.

٢-معامل الاختلاف الناتج من تصنيع النقاطات ( $CV$ ): وكان يحسب من المعادلة التالية:-

$$CV = \frac{s}{q'} x100$$

حيث أن :- $s$ = الانحراف القياسي للتصرف.

$q'$= متوسط تصرف النقاطات ( سم٣/دقيقة )

وقد أوضحت التجارب أن معامل الاختلاف يتأثر بإختلاف كل من ضاغط التشغيل ونوع الخطوط الفرعية حيث وجد أن الخط Typhoon أفضل الخطوط وكانت قيم الـ $CV$ له هي : ١٫٩٣ ، ١٫٣٠ ، ١٫٢٧ ، ١٫٧٠ ، ٢٫٠٢ ٪ وذلك عند ضواغط تشغيل ٣ ، ٦ ، ٩ ، ١٢ ، ١٥ متر علي الترتيب بينما كان الخط الفرعي Evaflow أقل الخطوط وكانت قيم الـ $CV$ له هي ١٢٫٤٣ ، ١٠٫٥٠ ، ٣٨٫٩٩ ، ٥٢٫٤٤ ٪ عند ضواغط التشغيل الآتية ٣ ، ٦ ، ٩ ، ١٢ متر علي الترتيب.

٣-توزيع تصرف النقاطات علي طول الخطوط الفرعية ( $q_i$ ) : تم قياسها بتجميع التصرف الناتج من النقاطات في مخبار مدرج خلال زمن محدد وذلك كل خمسة أمتار من بداية الخطوط الفرعية. وقد وجد من التجارب أن توزيع التصرف علي طول الخط يتأثر بالعوامل المستقلة السابقة حيث كان التصرف يزيد بزيادة كل من ضغط التشغيل عند بداية الخط وكذلك عندما يزيد ميل الخطوط الفرعية وهذه النتيجة كانت في جميع الخطوط ما عدي الخط الفرعي

RAM حيث أنه كان مزود بجهاز منظم للضغط Pressure compensated والذي يؤدي إلي ثبات التصرف عند زيادة الضغط ولكن من التجارب وجد أن تصرف النقاطات في هذا النوع يزداد بصورة كبيرة عند الضاغط ٦ متر مقارنة بالضاغط ٣ متر ولكن بعد ذلك وعند إستعمال الضواغط الاعلي من ٦ متر ( ٩ ، ١٢ ، ١٥ متر ) لوحظ إنخفاض ضعيف في التصرف وهذه من النتائج الجديدة والتي تم التوصل إليها. وكذلك الخط Evaflow وجد أنه أقل الخطوط إنتظاماً لتصرف النقاط علي طول الخط حيث كان التصرف في بداية الخط مرتفع جداً مقارنة بالتصرف في نهاية الخط خاصةً مع الضغوط المرتفعة وكان أعلي إنتظام في للتصرف في الخط الفرعي Typhoon للضغط الواحد.

٤-توزيع الضاغط علي طول الخط الفرعي ( $h_i$ ): تم قياسه بإستخدام مانومتر زئبقي كل خمسة أمتار من بداية الخط الفرعي. وكان الضغط يقل كلما إبتعدنا عن البداية وهذه بصفة عامة في جميع خطوط التنقيط وكان أفضل الخطوط إنتظاماً هو الـ Typhoon وكان أقلهم إنتظاماً هو الـ Evaflow نتيجة للإختلافات الناتجة في تصرف النقاطات وكان هذا في جميع ضواغط التشغيل وميول الخطوط الفرعية

٥-إختلاف تصرف النقاطات علي طول الخط ( $q_{var}$ ): وكان يحسب بإستعمال المعادلة التالية:-

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}}$$

حيث :- $q_{max}$= أقصي تصرف للنقاط علي طول الخط الفرعي ( سم٣/دقيقة )

$q_{min}$= أقل تصرف للنقاط علي طول الخط الفرعي ( سم٣/دقيقة )

وقد أوضح التحليل الإحصائي أن الاختلاف في تصرف النقاط تأثر معنوياً بضاغط التشغيل ونوع الخط الفرعي وكذلك ميله فقد وجد أن قيمة هذه الاختلافات هي ١٤٫٣٧ ، ١٤٫٧٣ ، ٤١٫٦٤ ، ٥٦٫٠٥ ، ٩٥٫٠٣ ، ١٤٫٣٦ ٪ وذلك للخطوط RAM , Ro-drip , Typhoon ,Ultradrip , Evaflow , Twiom علي الترتيب. وكذلك كانت القيم لضواغط التشغيل ٣ ، ٦ ، ٩ ، ١٢ ، ١٥ متر هي ١٨٫٨٨ ، ١٠٫٠٩ ، ١٠٫٣١ ، ٩٫٦٧ ، ١٠٫٢٣ ٪ علي الترتيب. بينما كانت هذه القيم ٢٨٫٩٥ ، ٢٧٫٥٧ ، ٢٨٫٢٣ ، ٢٧٫٦٦ ، ٣٠٫٦٠ ٪ للميول -٢ ، -١ ، صفر ، ١ ، ٢ ٪ علي الترتيب كما دلت النتائج علي أن أفضل ظروف للتشغيل وهي التي تعطي أقل إختلافات لتصرف النقاطات كانت للخط Typhoon عند تشغيله تحت ضاغط ١٥ متر وميل ٢ ٪ بينما كان أقل الخطوط تأثراً بهذه الاختلافات هي الخطوط Ultradrip and Evaflow عندما تم إستخدام ضاغط ٣ متر وميل -٢ ٪ في تشغيلهم.

٦- إختلاف الضواغط علي طول الخط الفرعي ( $h_{var}$ ) : وكان يحسب من المعادلة التالية:-

$$h_{var} = \frac{h_{max} - h_{min}}{h_{max}}$$

حيث أن :- $h_{max}$=أقصي ضاغط علي طول الخط الفرعي ( متر )
$h_{min}$=أقل ضاغط علي طول الخط الفرعي ( متر )
وقد أثرت العوامل السابقة تأثيراً عالي المعنوية علي هذه الاختلافات حيث أن إختلاف الضاغط ( $h_{var}$) كان ٧٥,١٢ ، ٤٣٫١٧ ، ٤١٫٥٤ ، ٤٥٫٨٣ ، ٨٨٫٢٩ ، ٥٤٫٨٦ ٪ وذلك للخطوط التالية:
RAM , Typhoon , Ro-drip , Ultradrip , Evaflow , Twiomعلي الترتيب. وعندما يقل كل من ضاغط التشغيل و ميل الخطوط الفرعية تزداد الاختلافات علي طول الخط حيث كانت ٧٢٫٨٧ ، ٤٢٫٥٦ ، ، ٣٠٫٦٨ ، ٢٣٫٦٣ ، ١٩٫٨٣ ٪ لضواغط التشغيل ( ٣ ، ٦ ، ٩ ، ١٢ ، ١٥ متر ) علي الترتيب ، بينما كانت هذه الاختلافات ٥٦٫٠٩ ، ٥٣٫٠٩ ، ٤٨٫١٤ ، ٤٥٫١٦ ، ٤٠٫١٨ ٪ لميول الخطوط الفرعية ( -٢ ، -١ ، صفر ، ١ ، ٢ ٪ ) علي الترتيب. كما وجد من التجارب أن أفضل نتيجة تم الحصول عليها كانت للخط ( Typhoon) وذلك عند إستخدام ضاغط تشغيل ( ١٥ متر) وكذلك الميل ( ٢ ٪ ) بينما كان الخط ( RAM) أكثر الخطوط تأثراً عندما تم تشغيله تحت ضاغط تشغيل ( ٣ متر ) وميل ( -٢ ٪ ) . أيضاً وجد من التجارب أنه كلما زادت إختلافات تصرف النقاطات زادت أيضاً إختلافات الضواغط .

٧-معامل إنتظام التوزيع ( $DU$): وهو مقياس يستعمل لتوضيح مشاكل التوزيع حيث أن قيمه المنخفضة دليل علي أن كمية المياه سوف ترشح إلي أسفل عندما يتم إضافة كمية المياه المناسبة لكل النباتات. ويتم حسابة من المعادلة التالية:-

$$DU=\frac{q'_l}{q'}x100$$

حيث أن : $q'_l$= متوسط ربع عدد النقاطات والتي كانت تعطي أقل معدل تصرف (سم٣/دقيقة)
وقد أثبت التحليل الإحصائي أن معامل إنتظام التوزيع فد تأثر معنوياً بجميع العوامل السابقة وقد وجد أنه يزداد بزيادة كل من ضاغط التشغيل و ميول الخطوط الفرعية فقد زادت قيمته بنسبة ٤٫١٦ ، ٤٫٢٨ ، ٤٫٠٦ ، ٤٫٣١ ٪ مقارنة بالضاغط ٣ متر والتي كانت قيمة ( ٩٢٫٣٧ ٪ ) وكذلك كانت نسبة الزيادة في معامل الانتظام ٤٫٤٩ ، ٨٫١٩ ، ٨٫٩٧ ، ٩٫٣١ ٪ مقارنة بالميل ( -٢) والتي كانت قيمة ( ٧٩٫٠٨ ٪ ) . وقد وجد من التجارب أن معامل الانتظام كان ٩٣٫٩٩ ، ٩٣٫٩١ ، ٨٢٫٧٩ ، ٧٣٫٤٣ ، ٢٤٫٥٧ ، ٩٤٫٩٢ ٪ للخطوط الفرعية RAM , Typhoon , Ro-drip , Ulteradrip , Evaflow , Twiomعلي الترتيب.

٨-فاقد الضاغط ( $\Delta H$): وهو عبارة عن الفرق بين قيمة الضاغط عند مدخل الخطوط الفرعية والضاغط عند نهايته.
ومن الدراسة وجد أن العوامل المستقلة السابقة كان لها تأثيراً عالياً المعنوية علي فاقد الضاغط والذي كان يزيد بإنخفاض ميل الخطوط الفرعية وكذلك بزيادة ضاغط التشغيل

وكان أقل فاقد في الضاغط هو ٨٥ ر٠ متر للخط الفرعي Ro-drip وذلك عند ٣ متر ضاغط تشغيل وميل ٢ ٪ بينما كان أقصي فاقد ٢٣ر١١ متر للخط الفرعي Evaflow عند ضاغط تشغيل ١٢ متر وميل -٢ ٪ وذلك لإنخفاض تصرف النقاطات بصورة معنوية خلال الربع الأول من طول الخط.

٩-معامل الإنتظام ( $UC$ ): تم حساب هذا المعامل من المعادلة التالية:-

$$UC = (1 - \frac{\Sigma|q - q'|}{nq'}) x100$$

حيث أن :- $n$ = عدد النقاطات التي تم قياس تصرفها

وقد أوضح التحليل الأحصائي أن جميع العوامل المستقلة تؤثر معنوياً علي معامل الإنتظام حيث كان الخط الفرعي Typhoon أفضل الخطوط وكانت قيمة معامل الإنتظام له هي ٤٣ر٩٩ ٪ عند ضاغط تشغيل ١٥ متر وميل ٢ ٪ علي الترتيب. بينما كان الخط الفرعي Evaflow هو أقل الخطوط إنتظاماً في تصرف النقاطات وكانت قيمة معامل الإنتظام له هي صفر ٪ عند ضاغط تشغيل ١٢ متر وميل -٢ ٪ .

ومن خلال النتائج المتحصل عليها يمكن ترتيب الخطوط الفرعية التي تم دراستها كالتالي: Twiom , Typhoon , RAM , Ro-drip , Ultradrip , Evaflow حيث كان معامل الإنتظام لها هي ١١ر٩٦ ، ٠٠ر٩٦ ، ١٢ر٩٥ ، ٧٨ر٨٨ ، ٤٨ر٧٦ ، ٣٥ر٢٣ ٪ علي الترتيب.

## الإستنتاج

قامت الدراسة بعرض لتصميم وآداء الخطوط الفرعية في نضام الري بالتنقيط . وقد وجد من نتائج التجربة أن العلاقة بين تصرف النقاط والضاغط عند النقاط ( $q-h$ ) تتفق ونتائج الأبحاث السابقة مع الخطوط الفرعية Twiom, Ro-drip, Typhoon, RAM بينما تختلف في حالة الخطوط الفرعية Ultradrip, Evaflow وقد أثر معامل الاختلاف الناتج من تصنيع النقاطات ( $CV$ ) في توزيع كل من تصرف النقاط والضاغط عند النقاط علي طول الخط الفرعي. والجدول التالي يلخص تأثير كل من نوع وميل الخطوط الفرعية وضاغط التشغيل علي الأتي : إختلاف تصرف النقاطات علي طول الخط ( $q_{var}$ ) ، إختلاف الضواغط علي طول الخط الفرعي ( $h_{var}$ ) ، معامل إنتظام التوزيع ( $DU$ ) ، فاقد الضاغط ( $\Delta H$ ) ، معامل الإنتظام ( $UC$ )

| العوامل | | $q_{var}$ (%) | $h_{var}$ (%) | $DU$ (%) | $\Delta H$ (متر) | $UC$ (%) |
|---|---|---|---|---|---|---|
| الخطوط الفرعية | RAM | ١٤ر٣٧ | ٧٥ر١٢ | ٩٣ر٩٤ | ٣ر٠٧ | ٩٥ر١٢ |
| | Typhoon | ١٤ر٧٣ | ٤٣ر١٧ | ٩٣ر٩١ | ١ر٧٦ | ٩٦ر٠٠ |
| | Ro-drip | ٤١ر٦٤ | ٤١ر٥٤ | ٨٢ر٧٩ | ١ر٦٨ | ٨٨ر٧٨ |
| | Ultradrip | ٥٦ر٠٥ | ٤٥ر٨٣ | ٧٣ر٤٣ | ١ر٩٦ | ٧٦ر٤٨ |
| | Evaflow | ٩٥ر٠٣ | ٨٨ر٢٩ | ٢٤ر٥٧ | ٣ر٩٩ | ٢٣ر٣٥ |
| | Twiom | ١٤ر٣٦ | ٥٤ر٨٦ | ٩٤ر٩٢ | ٣ر٢٩ | ٩٦ر١١ |
| ضاغط التشغيل (متر) | ١٥ | ١٠ر٢٣ | ١٩ر٨٣ | ٩٦ر١٠ | ٢ر٩٨ | ٩٧ر٣١ |
| | ١٢ | ٩ر٦٧ | ٢٣ر٦٣ | ٩٦ر٢٢ | ٢ر٨٤ | ٩٧ر٤٧ |
| | ٩ | ١٠ر٣١ | ٣٠ر٦٨ | ٩٦ر٠١ | ٢ر٧٦ | ٩٧ر٣٤ |
| | ٦ | ١٠ر٠٩ | ٤٢ر٥٦ | ٩٦ر٢٤ | ٢ر٥٥ | ٩٧ر٤١ |
| | ٣ | ١٨ر٨٨ | ٧٢ر٨٧ | ٩٢ر٢٧ | ٢ر١٩ | ٩٤ر٠٨ |
| ميل الخطوط (٪) | ٢- | ٣٥ر٩١ | ٥٦ر٠٩ | ٧٩ر٠٩ | ٣ر١٧ | ٨٠ر٧٧ |
| | ١- | ٣٠ر٠٤ | ٥٣ر٠٩ | ٨٢ر٧٤ | ٣ر٠٠ | ٨٣ر٦٩ |
| | صفر | ٢٨ر٢٣ | ٤٨ر١٤ | ٨٤ر٥٨ | ٢ر٧٧ | ٨٥ر٤٤ |
| | ١ | ٢٥ر١٨ | ٤٤ر٨٢ | ٨٦ر١٧ | ٢ر٦٢ | ٨٦ر٩٠ |
| | ٢ | ٢٣ر٦٤ | ٤٠ر١٧ | ٨٦ر٤٤ | ٢ر٤٠ | ٨٧ر١٥ |

# لجنــة الأشــراف

*الأستاذ الدكتور / يانو ، ت .*

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# أداء معدات الرى المختلفة
## ( تصميم وأداء الخطوط الفرعية فى نظام الرى بالتنقيط )

رسالة مقدمة من

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الله

بسم الله الرحمن الرحيم

قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ .

صدق الله العظيم
البقرة -٣٢-

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دكتوراه الفلسفة

فى

الميكنة الزراعية

قسم الميكنة الزراعية

كلية الزراعة بكفرالشيخ

جامعة طنطا

١٩٩٥