OPTIMAL NUMBER AND DISCHARGE RATE OF EMITTERS FOR COCONUT PALM IN SANDY LOAM SOIL

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

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2000

DECLARATION

I hereby declare that this thesis entitled **"Optimal number and discharge rate of emitters for coconut palm in sandy loam soil"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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Certified that this thesis entitled " **Optimal number and discharge rate of emitters for coconut palm in sandy loam soil"** is a record of research work done independently by Kum. Priya G. Nair under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

I have immense pleasure to express my deep sense of indebtedness, and gratitude to Er. P. Suseela, Assistant Professor, Dept of IDE, KCAET, Chairman of the Advisory Committee for her able guidance, constructive criticism and prolific encouragement during the course of this study.

I would like to express my heartful thanks to Dr. K. John Thomas, Dean , KCAET, for his profound encouragement and valuable guidance.

I have immense pleasure to express my whole-hearted gratitude to Dr. Ramachandran, Assistant Professor, Department of Farm Power Machinery and Energy, KCAET and Er. Abdul Hakkim, V.M., Assistant Professor, Department of Irrigation and Drainage Engineering, Members of the Advisory Committee for their advices and valuable suggestions during this research work.

I am very grateful to Dr. K.I. Koshy, Head, Department of Supportive and Allied courses, Dr. Noble Abraham, Assistant Professor, Department of Land and Water Resources and Conservation Engineering, Er. Suresh Kumar P.K. Assistant Professor, Department of Farm Power Machinery & Energy and Smt. Josephina Paul, Assistant Professor, Department of Supportive and Allied courses, for the timely help they rendered during this work.

I sincerely acknowledge the help and co-operation rendered by the farm supervisors and farm labourers during the time of fieldwork.

I also remain indebted to all my friends at KCAET, who helped me in completing this work successfully.

The award of Junior Research Fellowship by Kerala Agricultural University is greatly acknowledged.

At this moment, I thankfully acknowledge the blessings of my loving parents for their stable support through out the work.

Above all, I bow my head before the Almighty, whose grace has made me complete this task successfully.

Priya G. Nair

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SYMBOLS AND ABBREVIATIONS

Agric.	-	Agricultural
ASAE	-	American Society of Agricultural Engineers
cm	-	centi meters
congr.	-	Congress
CPCRI	-	Central Plantation Crops Research Institute
CPE	-	Cumulative pan evaporation
CWRDM	-	Centre for Water Resources Development and Management
Engg.	-	Engineering
et al.	-	and others
Fig.	-	Figures
g	-	gram(s)
ha	-	hectare(s)
h	-	hour
Int.	-	International
Irrg.	-	Irrigation
ISAE	-	Indian Society of Agricultural Engineers
J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
Kg/cm^2	-	Kilograms per square centimeter
Kpa	-	Kilo pascal
Lph	-	litres per hour
Ltd.	-	Limited
m	-	metre(s)
m^2	-	square metre(s)
mm	-	millimetre(s)
No.	-	Number
Proc.	-	Procedings
PVC	-	Poly Vinyl Chloride
Res.	-	Resources

Sci.	-	Science
Sec.	-	Second
Soc.	-	Society
Univ.	-	University
&	-	and
/	-	per
%	-	percentage
'	-	minute(s)
"	-	second(s)
o	-	degree(s)

Introduction

INTRODUCTION

Irrigation has long been recognised as an important factor for increasing agricultural production. It is an age old art, as old as the civilisation. Its importance is further enhanced as 70% of the country's population depend on agriculture for their livelihood. . In our country nearly 90% of the water consumed is for the production of crops in agricultural sector. Besides, the industrial and urban growth has given rise to more rapid expansion in non-agricultural demand for water. This leads to shortage of water, hence efficient and economical utlization of water for irrigation is very important.

Due to the uncertainty of the monsoon, agricultural productivity highly depends on irrigation . Moreover the introduction of 'Green Revolution' in the country which is based on high yielding varieties of seeds and heavy dosage of chemical fertilizers cannot be sustained without irrigation. In order to feed the increasing population, agricultural production should be increased, which necessitates an efficient irrigation system.

Improper irrigation may waste large quantity of water, soil nutrients and impair the productivity of soil. Water for irrigation and other uses has become more and more valuable due to the increased cost of irrigation projects and limited supply of good quality water.

Irrigation system that will provide highest yield per unit area with unit quantity of water, can be considered as an efficient system. Drip irrigation system is a proven technology to achieve this objective. This technology was developed in the early 1960's, is the slow application of water into the root zone of the crop.

Drip irrigation is based on the fundamental concepts of irrigating only the root zone of the crop (rather than entire area) and maintaining the water content of the root zone near optimum levels.

Irrigating only a portion of the land surface limits evaporation, reduces weed growth and minimizes interruption of cultural operations. Frequent application of water keep the soil at an optimum moisture condition for the growth of plant.

Drip or trickle irrigation has many desirable features like higher yields, reduced water and energy use (compared to sprinkler systems). It is also possible to use saline water with trickle system since the soil is kept at a higher water content and water contact with the plant is minimized compared to other types of irrigation systems. As the portions of the plant above the ground are normally completely dry, bacteria, fungi and other diseases causing pests that depend on moist environment are reduced when trickle irrigation is used. Drip irrigation system can be used for all wide spaced crops as in orchards, row crops, plantation crops etc.

The coconut palm (Cocos *nucifera* L), is one of the most useful palms in the world . It is grown in more than 80 countries of the world with a total production of 49 billion nuts per year. The world's largest coconut production is concentrated in the tropical region lying between 20° N and 20° S latitudes. About 100 to 225 cm of rainfall and 27 ° C temperature are suitable for its growth. India ranks third in the production of coconut (9283.4 million nuts),with Indonesia and Philippines being first and second respectively. The palm is cultivated mainly along the coastal tracts in Kerala, TamilNadu, Karnataka, Andhra Pradesh, Orissa, West Bengal, Pondicherry, Maharashtra and in the islands of Lakshadweep, Andaman and Nicobar.

Sandy loam soil is best suited for coconut cultivation. So coastal belts and the adjoining river valleys are particularly suitable for coconut farming. It can also be grown in red loams, light grey soil and well drained light black soil.

Coconut in India is mostly grown under rainfed conditions where varying periods of dry spell exist. Hardly 10% of the total coconut cultivated area in the country is irrigated. Availability of water to the palms depends mostly on the soil moisture status of the coconut growing soils. The rainfall pattern in the coconut growing tracts has been erratic, with the result that there exist long dry spells. Eventhough coconut can tolerate dry spells to some extent, continued long dry spells will adversely affect the growth and productivity of the palms. Long dry spells cause moisture depletion of soil which results in yellowing and drooping of leaves, reduction in female flowers, immature nut fall and button shedding. The water economy of the plants get adversely affected leading to other physiological and biochemical changes. All these ultimately lead to stagnation in growth, reduced leaf and flower production and depressed yields.

Now farmers in our country know very well that coconut production can be increased only by irrigating the palms in summer months. Different methods are adopted for irrigating coconut plantation. The traditional methods are flood irrigation and basin irrigation which results in deep percolation and evapotranspiration losses. The selection of a particular method depends on soil type, texture, climatic factors and topography of land.

In most parts of our country, especially in Kerala, plantation crops are grown in hilly regions. Conventional irrigation methods are not practical in these slopy terrains due to topographic limitations, high rate of water application and high energy consumption. In drip irrigation, quantity of water required is less and irrigation efficiency is very high. So these areas with limited water resources can be brought under drip irrigation for successful crop production.

Drip irrigation causes wetting of the soil only at the plant root zone. It involves slow application of water in the form of either drops or miniature sprays through mechanical devices called emitters at selected points along the water delivery line. In this method, it is possible to maintain the moisture level in the crop root zone at or near the field capacity during the entire growth period.

The recent years has seen major advances in the design, technology and management of the trickle irrigation. This is due to the better understanding of the movement of water in the soil in response to trickle emitter. A better trickle irrigation design depends on the information about the moisture distribution pattern under an emitter at different discharge rates. The soil type and the application rate of water, both influence the pattern of water movement in the soil

The shape and total volume of the wetted soil region below an emitter vary with hydraulic parameters of the soil, discharge rate of emitter and irrigation frequency. Very little attention is paid in the estimation of water distribution in the soil during trickle irrigation under realistic field conditions. So in this study an attempt is made to estimate the soil water distribution under trickle irrigation for coconut palms in sandy loam soil. The specific objectives of the study are:

1. To determine the moisture distribution pattern under drip irrigation in sandy loam soil.
2. To optimize the number of emitters, discharge rate, and duration of irrigation requirement for coconut palms.

Review of Literature

REVIEW OF LITERATURE

Drip irrigation is an efficient method for providing water and nutrients directly into the root zone of the plants, thereby eliminating soil erosion, runoff and deep percolation losses. The system applies water under pressure, the volume of which equal to the consumptive use of plants. This allows the soil moisture to be within the required range for plant growth. In this method lateral and vertical spread of water occurs inside the soil only to a limited extent. This has the advantage of wetting the soil surface generally 10 to 50 percent. Certain sophisticated systems of drip irrigation have in addition, provision for meeting the fertilizer needs of the plants by dissolving it in the irrigation water. It has many advantage over the commonly used sprinkler and surface flooding methods such as the potential for greatly improved efficiency in water use and successful irrigation of crops using saline water on marginal soils.

2.1 Advantages of drip irrigation system

2.1.1 Water Saving

Cole (1971) reported that drip irrigation resulted in considerable increase in water-use efficiency over furrow and sprinkler irrigation.

Sivanappan *et al.*(1972) reported that drip irrigation is suitable for fruits and vegetables and a saving of 80% in water use has been claimed under this system.

Sivanappan *et al.* (1975) conducted experiments with vegetables and cash crops and observed that water used in drip was only ½ to $^1/_5$ of that in the controlled surface methods.

Bruce *et al.* (1976) conducted studies on economic comparison of trickle and sprinkler irrigation for six fruit crops. The trickle irrigation was shown to be economical and advantageous in 6 out of 8 cases. The trickle system used 54% less water and 74% less energy per year in supplying the same amount of water to desired plants.

Griffin (1977) reported that growers using drip irrigation method indicated 25 to 50% saving in water, saving in operational costs, 25% higher yield and better quality of crop as compared to sprinkler systems.

Sivanappan (1977) conducted experiments to compare drip irrigation with conventional surface methods of irrigation and showed that drip irrigation save 80% of water, reduces weed growth and improves germination.

Sivanappan *et at.* (1983) reported that the economic advantages of the drip system are significantly impressive over the other methods of irrigation and water saved in the drip system can be profitably used for area expansion.

Mateos *et at.*(1991) reported a comparative study between drip and furrow irrigation for cotton. It was found that drip irrigation is advantageous under deficit irrigation conditions and water application efficiency was 30% higher in trickle irrigation system.

2.1.2. Increase of yield

Abrol and Dikshit (1971) compared drip method with conventional basin method of irrigation in India for onions and okra. They found significant increase in yield and water use efficiency in the drip method.

Grobeller (1971) reported that drip irrigated apple orchards produced 81.80% more yield than flood irrigated orchards during the previous season. In case of drip irrigated grapes, yield increase of 19% was obtained.

Fruits and vegetables are the primary recipients of drip irrigation system and they are made to flourish in the sandy soils of Israel deserts. This method was proved superior to other methods under desert conditions. (Sivanappan and Karai Gowder,1977)

Sivanappan and Padmakumari(1980) reported that the drip irrigated tomato crops at Coimbatore yielded 22.23 t/ha as compared to the corresponding control yield of 17.29 t/ha.

Khader(1982) obtained significant yield increase in arecanut by adopting the drip irrigation method. The drip irrigated palms showed higher percentage of fruit set and good vigor and saving of more than 50 percent of irrigation water compared to conventional method.

2.1.3. Salt water utilization

Goldberg *et al.*(1976) defined drip irrigation as a new agro-technical approach for growing crops under highly controlled conditions of soil moisture, fertigation, pest control and salinity. It has significant response on crop yield and timing of harvest. A number of farmers have taken up this system for coconut gardens, orchards and vegetable crops. Cost of the system depends on spacing of crops, type of materials selected and source of water.

Gupta and Tyagi(1984) studied effect of trickle irrigation and surface irrigation on the water use and salt accumulation. Compared with surface irrigation system, trickle irrigation results in 35% higher water use efficiency and 32% lower salt concentration.

Moolman(1988) studied the effects of spatial variability on estimation of soluble salt content in a drip irrigated saline loam soil. The salt content was found to increase exponentially with distance from the emitter.

2.2 Drip irrigation for coconut

Irrigation of perennial crops like coconut and cardamom in undulating terrain needs better understanding of the soil, climatic conditions and crop characteristics. To identify the best method of irrigation for these crops, it is not sufficient to have yield of plants alone as morphological and physiological characteristics of the plants also vary with the treatments. Such observations have greater practical application because of wide variations obtained with respect to soil moisture in the sloping terrain. One of the micro-irrigation methods suitable for widely spaced plantation crops is the drip irrigation method. Drip irrigation refers to those systems which cause wetting of only that part of the soil at the plant root zone. By drip irrigation method, it is possible to maintain moisture content in the root zone of the crop at or near the field capacity during the entire life cycle.

Nelliat and Padmaja(1978) conducted systematic studies on climatic approach on irrigation requirement of West Coast Tall(WCT) coconut palms. The response to three depths of irrigation water (IW) namely 20,40 and 60 mm at three frequencies based on IW/CPE ratios of 1.0,0.75 and 0.5 revealed that irrigation at IW/CPE of 1.0 and 0.75 significantly increased leaf number, female flower production and yield over the IW/CPE ratio of 0.5

Mathew (1986) conducted a study on irrigation in coconut gardens. The study showed that irrigation is necessary for coconut palms in summer months. The irrigation in summer season increases the yield of 20 to 30 nuts per palm. The amount of water needed for each irrigation depend on root zone area and moisture holding capacity of soil.

Muralidharan(1988) conducted study on different irrigation methods for coconut gardens. The results revealed that drip irrigation economize water use efficiency by 50-70% of the traditional systems. Besides, it was reported that 30-40% increase in yields could be obtained by the adoption of this system.

Nagaraj *et al.* (1988) conducted study on economics of drip irrigation for coconut plantations. The study revealed that among several methods of irrigation, drip irrigation system is gaining importance especially for orchards and row crops, on account of the economics of water use.

Studies conducted at CWRDM on the yield of coconut and rubber under drip irrigation showed that more than 50% reduction in the quantity of water applied can be obtained per tree under drip irrigation compared to basin irrigation. (Anonymous, 1989)

Nair and Menon(1990) reported that drip irrigation technique developed for coconut gardens supplied daily water need of 32 litres per palm in dry months at 4 dripping points located at 1 meter distance from the bole around the palm. The water was allowed to drip at about 30 cm below the soil surface at the rate of 2 litres/hour. This eliminates loss of nutrients by leaching and a saves of about 40% of water compared to basin system.

Nair(1991) reported that drip irrigation is more suited for plantation crop like coconut and water can be saved up to 70%. The study also showed that the water requirement of coconut palm ranged between 30 to 50 litres per day.

Njanadevan(1991) reported that drip irrigation is more suitable for growing coconut in water scarcity areas. Evaporation, percolation and nutrient losses are less compared to other methods. The drip irrigated coconut palm give more growth and early flowering.

Ramani Gopalakrishnan(1991) reported that by adopting drip irrigation in coconut gardens water and energy can be saved up to 80%. Besides this, yield increase of 40-50% was observed.

Nambiar(1992) reported that drip irrigation is the best water application method for irrigating coconut field among the other irrigation methods. The main advantage of this system was saving of water up to 80% and maintenance of soil fertility without nutrient loss.

Yusuf and Varadan(1992) found that drip irrigation is most suitable for water scarcity areas. In littoral sandy soil at Kasaragod, 32 litres/palm/day through drip produced 38% higher nuts than basin irrigation with 200 litres/ palm/four days.

Mathewkutty(1998) reported that the drip irrigation is more suitable in water scarcity areas. This method is profitable in soils having low water holding capacity and having mild slope. The water requirement was one third of other methods and evaporation and deep percolation losses were minimum.

Dhanpal *et al.*(1999) conducted studies on the coconut root absorption. The study indicated that 0.75 m to 1.25m away from the bole is the active absorption zone and hence it is recommended to place the emitter or micro tubes in the centre of that area. The water spread from a single point source revealed that at least four emitters are required for the laterite and red sandy loam soil, whereas for the sandy soil six emitters are required.

2.3. Soil moisture distribution pattern in different soil types.

A perfect knowledge of trickle irrigation requires the knowledge of water distribution pattern in a soil under trickle irrigation with various discharge rates. The knowledge of moisture distribution pattern will determine the effectiveness of trickle irrigation. The design of trickle irrigation system mainly involves the determination of lateral and emitter spacing which is a function of wetted area of crop root zone. Water moves through soil profile under gravitational and capillary forces. It normally wets only a part of the potential soil root zone. The distribution pattern resulting from isolated point source wets the soil bulb axially symmetrical rather than in one-dimensional fashion. The soil wetting pattern is controlled by emitter discharge rate and irrigation regime, which in turn is determined by frequency and amount of irrigation and crop water use. By careful design and management of drip system it is possible to create and maintain soil moisture conditions that promote or if necessary control crop growth. The findings of moisture distribution pattern study will be useful in designing system especially for deciding optimal spacing of emitters and laterals.

Remadevi and Michael(1983) conducted study on soil moisture distribution pattern with respect to different discharge rates and salinity levels from micro irrigation system. The profile of soil moisture front ,wetting from the application of water at a point source was semi-elliptical in shape. The relationship between vertical and horizontal advance of soil moisture versus elapsed time was described by standard equations. The results were used in the design of optimum rate of water application with micro irrigation technique.

Padmakumari and Sivanappan(1988)carried out a study to identify how best to adjust the drip system to the soil hydraulic properties and crop requirements. The relationship identified that the saturation zone and discharge rate, can be used to design emitter spacing.

Fangmeir *et al.*(1989) irrigated cotton 2 to 3 times weekly using buried perforated tubing under each row. Water application rates were about 0.6,1.0 and 1.3 times of estimated consumptive use. Significant differences in seasonal average crop water stress values, average soil moisture contents and yields were obtained for the 3 water treatments. The wettest treatment with average crop water stress index value near 0.1 gave the highest yield and highest soil water contents before irrigation. The yield increased nearly linearly with decrease in crop water stress.

Rissie and Chesness(1989) developed a simplified design procedure to determine the wetted radius for a trickle emitter. Field tests in a sandy loam peach orchard at two emitter flow rates showed that predicted wetted radius values were within the range of 11% and 19% of measured values.

Ahkoon *et al.* (1990) reported the influence of drip irrigation emission rate on distribution and drainage of water beneath a sugarcane and fallow plot. Soil hydraulic potential was measured intensively and regularly by a three dimensional array of tensiometers. The study investigated the effects of three emission rates (1, 2 & 4 lph) using drip irrigation on the distribution and drainage of water beneath sugarcane crop and a fallow plot. The fastest rate of emission (4lph) resulted in greatest lateral spread of water but emission rate did not affect the amount of drainage. More drainage occurred beneath the drip line than farthest from it and contrary to the expectation, maximum loss by drainage was found to be beneath the point half way between the emitters. This was interpreted as due to the overlapping pattern from adjacent emitters. The result also showed that adoption of emission rate of 4lph and wider spacing between emitters(75cm) allow the irrigation of a greater cane area.

Batchelor *et al.*(1990) studied the soil moisture conditions created under drip irrigation. The study describes a trial to determine the most appropriate combination of irrigation regime, drip line placement and row spacing for drip irrigated sugarcane grown under local conditions. The distribution of soil water potential on each 14 treatments were done using two-dimensional array of tensiometers. The data of soil moisture potential were taken for each treatment. The data were used to explain differences between treatments in both cane growth and yield. Periods of over and under irrigation were identified

Bell *et al.*(1990) conducted a study on soil water status, expressed in terms of soil water potential for soil water relations in drip irrigated sugarcane trials in Mauritius. The study revealed that unlike surface or overhead irrigation, soil water distribution resulting from drip irrigation is not one dimensional. Soil water potential data derived from vertical arrays of tensiometers set out across the crop row/drip line units were used to plot and quantify the soil water distributions resulting from many different treatments and regions.

Gregory (1990) conducted a study on soil physics and *irrigation*. Soil physical knowledge has contributed substantially to understand how much water to apply to rewet the soil and how water is distributed away from points of application. The results showed that rooting depth and distribution of moisture contributed to the actual rate at which water was utilized and the preferential wetting of limited soil volume can modify this feature.

Hodnett *et al.* (1990) described a method for scheduling the drip irrigation for sugarcane using index tensiometers. Water was applied to a point in the profile *near the drip line inorder to keep the root zone* at a *constant soil moisture* potential. The quantities of water to apply each day were estimated from the tensiometer readings using simple guidelines. A field trial was run to compare the index method of control with irrigation control. With the latter method of irrigation control treatment, the amount of water applied was (1.0 ETc) or half of this (0.5ETc). The amount of water applied to the index treatments lay between that applied to treatments given 1.0 ETc and that given to treatments receiving 0.5 ETc. The result showed that yield obtained using index control were slightly better than with the irrigation control.

Abbott and Ahkoon (1992) reported the contrasting soil moisture environments in drip irrigated cane during day and night at two plots. Soil moisture environment under each treatment was monitored using two dimensional arrays of tensiometers across the middle of cane row. The data revealed a diurnal cycling of matric potential on both plots due to irrigation application and root water abstraction. Considerable differences in size and duration of wet bulb were also seen, showing that irrigation application has a significant effect on soil moisture environment beneath the crop.

Omary and Ligon(1992) developed a finite element for three dimensional movement of water and pesticide from trickle irrigation. The model considered unsaturated, non-steady flow in a multi layered soil, taking into account of reactive and degradable pesticide. Linear and first order equations were used to describe the adsorption and degradation of the pesticide. The finite element technique was used in solving the non-difference scheme to solve the time dependent part of the equations.

Phadtare *et al.* (1992) conducted a field experiment to study the moisture distribution pattern of trickle irrigation in vertisol. Fixed quantity of water (12 litre) was applied during test from a single point source. The result showed that at the surface, radial spread of 31 cm and 26.25 cm were observed for lowest (2 lph) and highest (5 lph) discharge respectively. The vertical advance were 105.65 and 118.5 cm for 2 lph and 5 lph emitter discharge respectively.

Sarkar and Kar(1992) estimated the water uptake pattern of groundnut from different soil layers. The water uptake data were analyzed using one dimensional flow equation for water movement in the soil and treating the root system as distributed sink term. Sink term was determined by the evaluation of water content and soil water flux distribution as a function of depth and time. Root water uptake was higher in the near surface (0.3-0.7m) as compared to very near the surface (0.0-0.3m)and lower (0.7– 1.0m) layers. The zone of maximum uptake moves downward with time. In dry soil, water flux played the dominant role in controlling water extraction rate.

Vellidis and Smajstrla (1992) developed a mathematical model to simulate soil water infiltration, redistribution and extraction in a bedded soil profile overlaying a shallow water table and irrigated by a line source drip irrigation system. The model was then used to simulate two dimensional soil water movement as observed in lysimeter study. A bedded and plastic mulched soil profile irrigated by a line source drip system influenced by a shallow water table was studied in the lysimeter. The model results were in good agreement with the lysimeter data collected.

Amir (1993) reported a study related to lateral and longitudinal wetting patterns of very low energy moving emitters. A set of experiments were conducted to investigate the wetting contours obtained under very low pressure (10-15 Kpa) moving emitters. 9 different instantaneous application rates (IAR) were applied by 3 water amounts. Results showed that high IAR increases uniformity of wetting pattern and its width and decreases the depth. But high IAR increases water ponding on soil surface, and consequently runoff. The results of wetting patterns under moving emitters are in good agreement with those for source-point stationary emitters.

Andreas *et al.*(1993) reported the soil water distribution under trickle source. Soil water distributions in homogenous soil profile of yolo clay loam and yolo sand irrigated from a circular source of water were measured at seven times after initiation of irrigation. The effect of trickle discharge rates and soil types on the locations of wetting front and soil water content distributions were determined. A finite element solution of the 2 dimensional transient soil water equation, the theory of time dependent, linearlised infiltration from a circular source, the effective hemisphere model and generalised solution for axially symmetric flow were compared with experimental results. In general, computed vertical advances of the wetting front were closely related to those observed for both soils. Soil water content distributions computed by linearlised and numerical solutions, agreed reasonably with measured values in both soils.

Carmi *et al.(*1993) conducted a study on effect of soil water distribution on cotton root growth. The study showed that capability of mature cotton plant roots to adjust their growth to large changes in water distribution in the soil is slow. This should be taken into account for determination of irrigation regime in which the depth of water application was changed during the growing season.

Michelakis *et al.*(1993) reported the effect of 3 water use (WU) levels corresponding to 0.3,0.6, 0.9 Ep (evaporation A pan) on wetted soil volume, root distribution and yield of avocado over a 5 year period. The average amount of irrigation water applied annually (in addition to rain) for 3 WU levels were 238,553 and 868 mm. Soil water content percentage (θ) corresponding to a soil water potential (Ψs) higher than-0.1 Mpa increased markedly from 0.3 to0.6 Ep and slightly from 0.6 to 0.9 Ep. WU levels being 26.3 , 41.7 and 52% respectively. Water saving, deep percolation, wetted soil volume, root development and yield quantity and quality were taken into account, then WU level of 0.6 Ep can be considered optimal under this conditions.

Clothier and Green (1994) reported the rootzone processes and efficient use of irrigation water for kiwifruit vine. Time domain reflectometry observations of the changing soil water content in the rootzone of the kiwifruitvine, and direct measurement of sap flow within the individual roots, both revealed that plants can rapidly change their spatial pattern of water uptake in response to the application of irrigation water.

Dahiwalkar *et al.*(1994) conducted a study on pressure discharge relationship and moisture distribution pattern of drip irrigation in sandy clay loam in pomegranate orchard. The results revealed that at low operating heads and at corresponding low discharges the vertical advance was higher. Similarly for high operating heads and at corresponding high discharges the horizontal advance was higher.

Shu-Jung (1994) reported green-ampt analysis of wetting patterns for surface emitters. A 3 dimensional green-ampt analysis was developed, and the infiltration capacity curve represents the time distribution of wetting pattern. The infiltration-capacity curve was applied to describe the wetting pattern of surface emitter with a constant discharge by matching the emitter discharge with average infiltration capacity curve.

Singh and Joseph(1994) conducted study on kinematic wave model for soil moisture movement in unsaturated soils with plants. The analytical solutions were derived which showed that the plant roots were assumed to extract soil moisture at constant rate and the upstream boundary condition was independent of time.

Steevens and Douglas(1994) conducted a study on distribution of grapevine roots under drip irrigation using salty water. Under drip irrigation, roots were concentrated below the vine row, where as in microjet irrigation, roots were evenly spread across the planting area. Based on the variation of root length/unit area across a quarter of planting area and between vines it was concluded that selection of location at which root length/unit area (La) would be representative of that in the entire irrigation unit ,was feasible in micro jet irrigated vines. The absence of location of representative area confounds the scheduling of drip irrigation solely on measurements of soil moisture.

Whalley *et al.* (1994) developed a design on integrated system which has the capability to measure simultaneously water content and matric potential. Water content was measured using time domain reflectance and matric potential was measured by tensiometry.

Zur *et al.*(1994) developed a new approach for the estimation and control of the quantity of water applied in an irrigation. In this, irrigation was stopped when the wetting front reaches a critical depth Z_L. An expression for calculating critical depth was developed. A major parameter in this expression was velocity of advance of wetting front 'V' which was shown to be directly related to application rate, IR and inversely related to initial soil moisture content θ_E.

Bhardwaj *et al.* (1995) reported that the soil water distribution was uniform at 0 to 0.15 and 0.15 to 0.20metre depths and decreased as soil depth and distance from dripper increased. The uniform distribution of soil moisture under drip irrigation was reflected in plant growth, as shoot length and trunk girths in this treatment.

Coelho and Or(1996) conducted a study on flow and uptake patterns affecting soil water sensor placement, a key factor in the performance of soil water based drip irrigation scheduling schemes. The uncertainty in these sensor locations may be large due to the high sensitivity of such point measurements to minute variations in wetting and uptake patterns. A proper selection of sensor placement hinges on accurate description of soil water dynamics.

Or and Coelho(1996) conducted studies on soil water dynamics under drip irrigation. Advances in drip irrigation management rely on knowledge of the distribution and dynamics of soil water within the wetted soil volume. Part of the information can be obtained from numerical and analytical models for water flow from point or line source. A more complex picture of soil water dynamics in cropped fields requires explicit consideration of plant water extraction patterns. In this study transient uptake pattern was represented by an array of buried line sinks of different strengths determined by a new parametric uptake model. In addition, a point approximation was proposed based on localized water balance which considers changes in water content due to transient flow from the dripper coupled with plant uptake only from the soil volume under consideration. The two methods offer reasonable means to describe soil water dynamics within wetted soil volume under cropped conditions for various irrigation management scenarios.

Lubana and Narda (1998) developed a soil water dynamic model for establishing the wetting pattern of point source trickle emitters under a tomato crop. Infiltration from the point source trickle emitters in the presence of water extraction has been investigated by assuming a hemi-spherical shape of the wetted soil volume and analytical expressions have been derived for determining the position of wetting front. Water extraction by plants has been estimated by using a macroscopic model. Daily values of water uptake has been used to update the volumetric moisture content in the root zone layer. The values of soil moisture content predicted by the model compared well with field observed values. The predicted values were used to predict the radius of hemisphere of wetted soil volume which forms a basis for deciding emitter spacing for various crops and operating conditions.

Materials and Methods

MATERIALS AND METHODS

Information regarding various soil properties like soil texture, bulk density, field capacity, infiltration rate, wilting point, saturated hydraulic conductivity and crop characteristic are important in deciding the irrigation practices of a crop. Improper irrigation may waste large amount of water and nutrients and hence reduce the productivity of the soil. An irrigation system, which will provide highest yield per unit area per unit amount of water, can be considered as an efficient irrigation system. Drip irrigation can be considered as an efficient irrigation system since it maintains moisture content in the root zone within the optimum condition and increases the productivity of the soil. An efficient design of a drip irrigation system should have correct spacing of lateral and emitters. For deciding the correct spacing of the emitters, a perfect knowledge of soil moisture distribution pattern under the emitter at various discharge rates should be known.

With the drip irrigation, if the discharge rate of the emitter exceeds the infiltration capacity of the soil, a ponded area may occur around the emitter. The size of the ponded area is a function of discharge rate of emitters and infiltration rate of soil. This necessitates the study of soil moisture distribution pattern for different types of soil and discharge rates as a guide for the efficient design, operation and management of a trickle system. In trickle irrigation, both vertical and horizontal wetting fronts are important. One of the most important considerations in the design of trickle system is the volume of soil wetted by a single emitter. This must be known to determine the total number of emitter required to wet enough volume of the soil to satisfy the plant's water need. The present study was conducted in a coconut field for observing the soil moisture distribution pattern under the trickle source for different combinations of number and discharge rate of the emitters. The materials used and methods adopted for conducting experiment, data collection and analysis are presented in this chapter.

3.1 Location and Climate

The experiment was conducted in the coconut garden of Instructional farm, KCAET, Tavanur. It is situated at 10^0 53'30" north latitude and 76^0 east longitude. The total area of KCAET is 40.99 ha, out of which total cropped area is 29.65 ha. Agroclimatically, the area falls within the borderline of Northern Zone and Central Zone of Kerala. Major part of the rainfall received in this region is from SouthWest monsoon. The average annual rainfall of the region varies from 2500 to 2900 mm. The coconut palm grown in the experimental field is 15 year old TxD. The experiment was conducted during January-May months of 1999. The climatological data of the experimental area is shown in the table 1.

3.2 Soil Properties

The soil physical properties like texture, structure, density, porosity, water content, infiltration capacity, field capacity and permanent wilting point are the dominant factors which determine the availability of oxygen in the soil, the mobility of water through the soil, availability of water to the crop and ease of root penetration. Texture is an important soil characteristic since it affects infiltration rate, water storage in the soil, ease of tilling the soil, the amount of aeration and influence the soil fertility. Knowledge of bulk density is of particular importance in the determination of moisture content and other chemical and physical properties of the soil. It can also be used to estimate differences in compaction of a soil. The infiltration process influences runoff, and determines the water content of the soil. Permeability (hydraulic conductivity) is proportional to the square of average particle size in a soil. The field capacity and permanent wilting point are the upper and lower range of moisture available to the plant which will influence the plant water uptake.

Table 1 Climatological data of experimental area

Mean Maximum temperature	32.5°C
Mean Minimum temperature	22°C
Average Relative humidity	83%
Average annual rainfall	2700mm
Mean Evaporation (CIA pan)	6 mm/day
Mean solar radiation	85 w/m^2/day
Number of rainy days	125

3.2.1 Soil texture

The particle size analysis, for finding out the percentage of various sizes of particles in a dry soil can be performed in two stages, sieve analysis for coarse grained fraction and sedimentation analysis for the fine grained fraction.

In this study, composition of soil was determined by sieve analysis and hydrometer method. The soil was collected from the experimental field at a depth of 75cm from the soil surface by using an auger. The soil sample was then oven dried and passed through a set of IS sieves of size 4.75mm, 2mm, 1mm, 600 micron, 150 micron and 75 micron for sieve analysis. The percentage finer was calculated on the basis of percentage of soil retained in each sieve.

For particles finer than 75 micron, sedimentation analysis was done using density hydrometer. The calibration of hydrometer was done. 100ml sodium hexametaphosphate solution was added to the dry soil sample passing through 2mm IS sieve. It was then warmed for 10 minutes and was mixed thoroughly for 15 minutes. The soil suspension was then transferred to 75 micron IS sieve placed on a receiver and washed the soil on the sieve using jet of distilled water. The distilled water was added to the soil suspension to make the volume exactly to 1000ml. A rubber bung was inserted on the top of 1000ml measuring cylinder containing soil suspension and shaked it vigorously. The suspension was allowed to stand for sometime. The cover of the cylinder was removed and stopwatch was started immediately. The hydrometer reading was taken after ½ minute by inserting the hydrometer in the solution. Similarly the readings were taken at 1,2,4,8,15,30,63,113,240,513,1408 minutes. Particle size was obtained for each hydrometer reading by using the formula

$$D = 10^{-5} \pm \sqrt{He/t}$$

Where D - Particle size (mm)

F -A factor which depends on the specific gravity of soil and temperature of the solution.

He – Effective depth obtained from the calibration chart, cm

T – Elapsed time (min)

The particle size distribution curve was drawn with percentage finer 'N' as the ordinate and particle diameter (mm) as the abscissa.

3.2.2 Bulk density

The core cutter method was adopted to determine the bulk density. Soil sample was collected by using the core sampler. The weight (W_2) and volume (V_1) of the soil sample in the core cutter were noted. The sample was then oven dried and weighed again (W_3). Bulk density was calculated using the relation.

$$\text{Bulk density} = W_3/V_1$$

3.2.3 Field capacity

A soil surface of 2sqm was wetted to the saturation level and was left to drain for 2 days. The surface was covered with a PVC sheet to prevent the evaporation. Soil samples were collected with an auger from different depths at one hour interval each after 12 h, till the values of moisture content in two successive samples are nearly equal. This constant value of moisture content is considered as the field capacity of the soil. A graph was plotted with time (hrs) on the X-axis and percentage moisture content on the Y-axis.

3.2.4 Infiltration rate

Infiltration rate was determined by using double ring infiltrometer. It consists of two cylinders of 25cm deep and are made of 2mm rolled steel. The cylinders were driven into the soil with the help of a hammer. The outer cylinder which is 60cm in diameter is used to form a buffer pond to minimise the lateral spreading of water. The infiltration measurements were taken from inner cylinder of 30 cm diameter. A constant head was maintained by pouring water into the cylinders. The hook gauge measurements were taken at frequent intervals to determine the amount of water infiltrated during a particular time interval. Water was added quickly after each measurement to maintain a constant average infiltration head. The readings were taken till a successive constant value was obtained. The test was replicated at different locations in the field. The average values of accumulated infiltration (Y) and infiltration rate were found out. A functional relationship was developed by using the equation

$$Y = at^{\propto} + b$$

Where Y – Accumulated infiltration (cm)

t – Elapsed time (min)

$a, \propto, b$ – Constants

The values of the constants $a, \propto, b$ were found out.

3.2.5 Wilting point

500g air-dried soil was filled in five cans having a drain hole at the bottom. A dwarf sunflower was selected as an indicator plant as it exhibits the symptoms of moisture stress early and has a root system which penetrates the soil mass uniformly and rapidly. Four seeds of sunflower were sowed in each can and were allowed to germinate. After germination, two of them were allowed to pass through the holes in the PVC sheet, placed above the soil surface. The plants were allowed to grow six weeks by watering them when needed. The soil surface was plugged with cotton wool and a glass tubing was inserted for soil aeration. At this stage, plants were watered for the last time. The plants along with the can were transferred to dark humid chamber if it showed the sign of loss of turgor. When the plants regained turgidity, they were exposed to the atmosphere for a couple of hours and then transferred back to the humid chamber. The process was repeated till the plants do not recover. At this stage, the plants along with its roots were removed from the can. The moisture content of the soil in the can was noted, which represents the wilting point of the soil.

3.2.6 Saturated hydraulic conductivity.

The undisturbed soil samples were collected randomly from 3 locations in the field. In each location, core soil samples from depths of 0-12, 12-24, 24-36, 36-48, 48-60 and 60-75cm were collected using core sampler. After saturating the samples in a tray of water for one hour, the samples were processed and placed in constant head permeameter experiment set up. The water supply was given to the constant head permeameter. The soil column length, L (cm); the head of the water over the soil column, h (cm) etc. were noted. A measuring cylinder was placed below the soil column to collect discharge. The water was allowed to infiltrate and discharge was measured once in 10 minutes and the process was repeated till the consecutive constant values were reached. Saturated hydraulic conductivity was calculated by using the Darcy's law

$$Ks = Q/t \times L/h \times 1/A$$

Where Ks – saturated hydraulic conductivity (cm/sec)

Q – quantity of flow (cm^3)

t – time (sec)

L – length of sample (cm)

h – hydraulic head (cm)

A – cross sectional area of sample (cm^2)

The mean value of Ks was found out.

3.3 Experimental details

A field experiment was conducted to optimize the number of emitters, discharge rate and duration of irrigation required for coconut palm by observing the moisture distribution pattern of the drip emitters. The experiment was conducted at the Instructional farm, KCAET, Tavanur. The size of the experimental field is 28x63m planted with 24 coconut palms at a spacing of 7 meters each. The experiment was conducted during the months of January to May when the irrigation demands would be the highest.

3.3.1 Experimental layout

The statistical design was a randomised block design with four replications. The layout of the experimental field is shown in Fig 1. Two different discharge rates and three number of combinations of emitters were randomised in four replications. The treatments are as follows.

T_1 – 3 number of emitters of 4 lph discharge

T_2 - 3 number of emitters of 8 lph discharge

T_3 – 4 number of emitters of 4 lph discharge

T_4 – 4 number of emitters of 8 lph discharge

T_5 – 6 number of emitters of 4 lph discharge

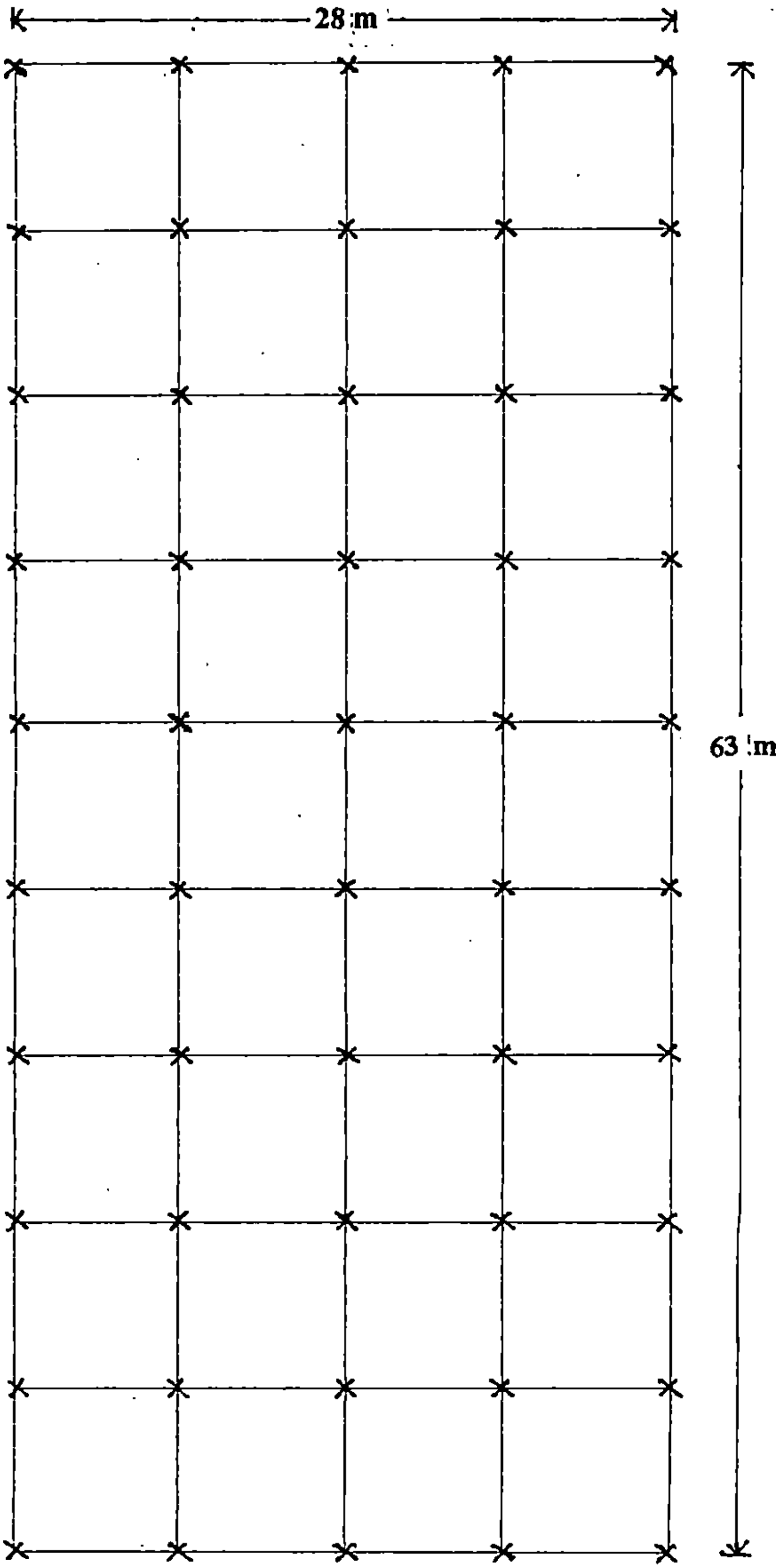
T_6 - 6 number of emitters of 8 lph discharge

3.3.2 Drip system installation

The drip system was installed in the field as shown in Fig 2 and Plates1&2. Studies conducted by Dhanpal *et al.,* (1999) reveals that 0.75m to 1.25m away from the bole is the active absorption zone and hence the emitters were laid at 1m away from the bole. Equally spaced emitters were laid around the tree. Arrangement of emitters around the tree in different treatments is shown in Fig3. The water supply to the main line was obtained from a hydrant near to the experimental field. A screen filter was fitted in the main line inorder to avoid the clogging of the emitters. A pressure gauge was fitted on the main line to check whether a constant supply head is maintained.

3.3.3 Irrigation Requirement

Crop water requirement is the most important factor for determining the irrigation requirement. Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration (ET crop) of a disease free crop, growing in large fields under non restricting soil condition including soil water and fertility and achieving full production potential under the given



Scale

1:3

Fig. 1 The layout of the experimental field

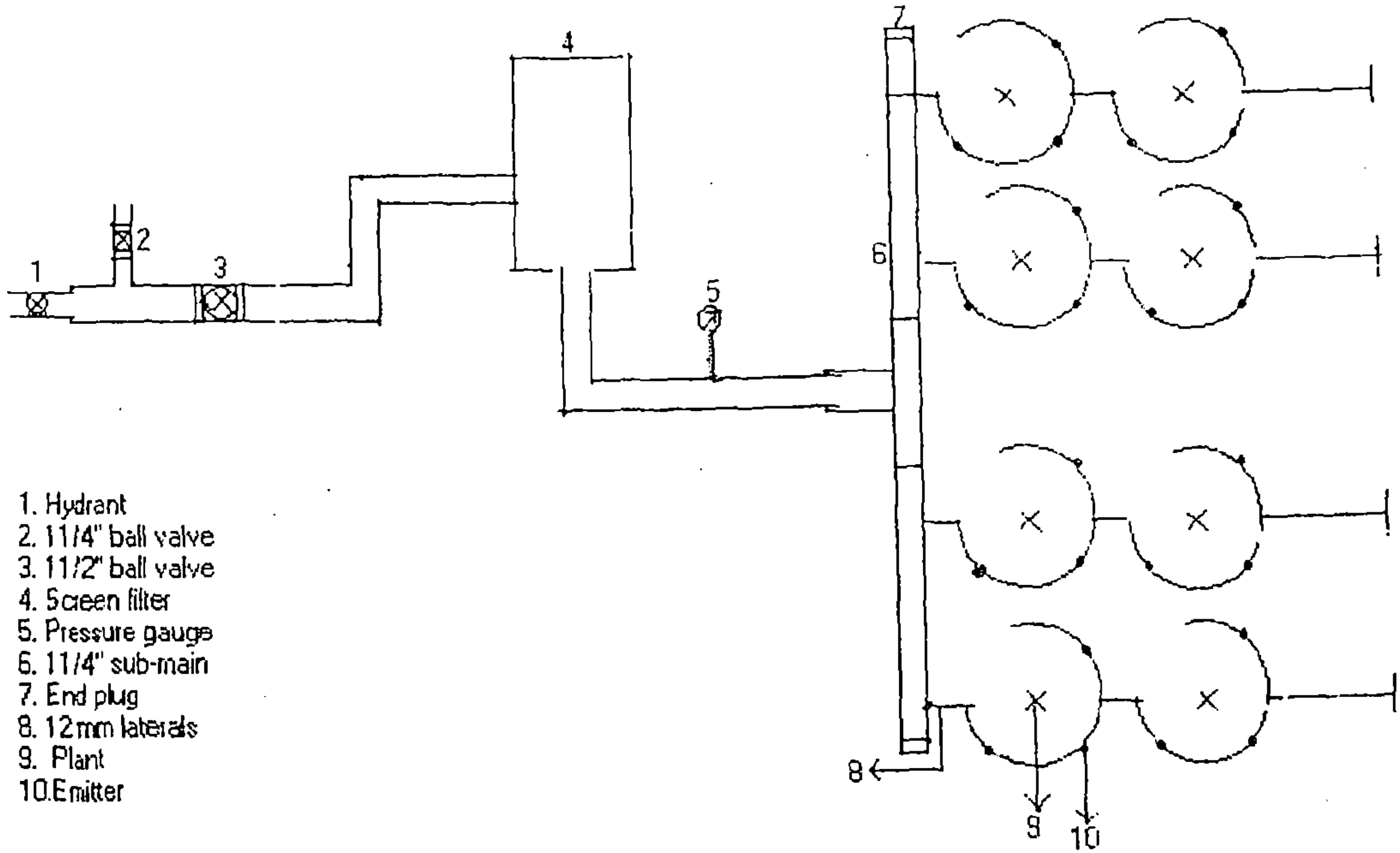
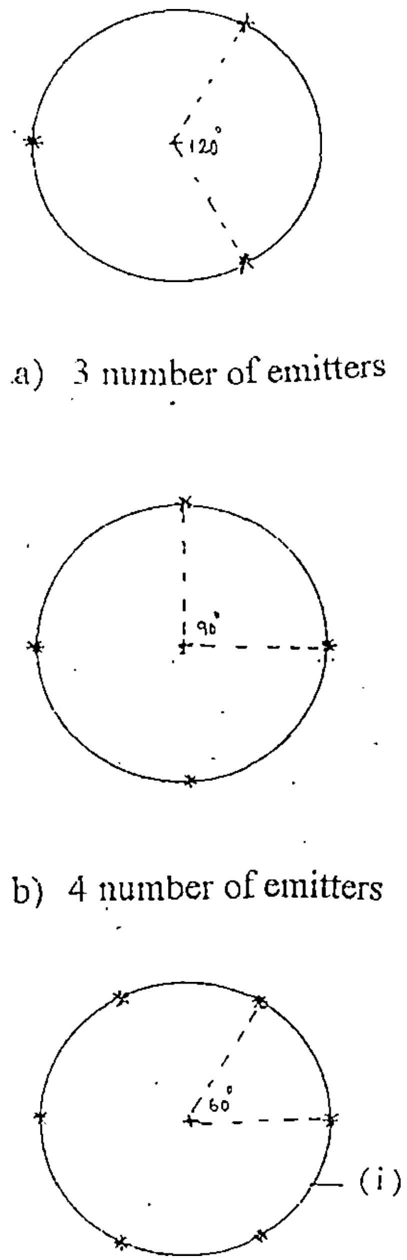


Fig. 2 Schematic representation of experimental setup.

Plate No. 1 A view of the experimental plot

Plate No. 2 Experimental setup showing the filter assembly



a) 3 number of emitters

b) 4 number of emitters

c) 6 number of emitters

(i) Lateral

+ Plant

* Emitter

Fig. 3 Arrangement of emitters around the tree in different treatments environment. The effect of the crop characteristics on crop water requirements is given by the crop coefficient (Kc) which represents the relationship between reference crop evapotranspiration (ETo) and crop evapo- transpiration (ETcrop)

i.e. ET crop = Kcx ETo.

Pan evaporation method was used in this study to calculate ETo values. ETo was calculated by using US weather Bureau class A pan. The pan made of 22 gauge galvanised iron, 120cm in diameter and 25 cm in depth and is painted white. It was exposed on a wooden frame inorder that air may circulate beneath the pan. It was filled with water to a depth of 20cm. The water surface level was measured at 7 A.M. everyday by means of a hook gauge.

Pan evaporation (Epan) was computed as the difference between the consecutive readings. The pan may have higher evaporation rate than a large free water surface. Hence a factor 0.7 is usually recommended for converting the observed pan evaporation (Epan) to reference crop evapo-transpiration (ETo). The crop water requirement is calculated by multiplying the ETo value with crop coefficient (Kc). The Kc value for the coconut is 0.75. Hence the daily water requirement of coconut (ETcrop) is ET crop = 0.7x0.75xEpan.

Since there was no rainfall during the period of experiment, the antecedent moisture content was negligibly small and not taken into account. Due to this reason, the calculated water requirement was taken as the irrigation requirement. The volume of water applied to each treatment palm was regulated by adjusting the time of operation

3.4 Vertical and Horizontal advance of water

3.4.1 Horizontal wetting front with respect to time

Immediately after the water flow started from the dripper to the soil surface ,the radius of ponded zone and wetting zone as a function of time was noted by using a stop watch and a measuring scale. After the ponded zone reached a steady state (rate of change of ponded radius with respect to time is zero), advance of wetting front with respect to time alone was noted.

3.4.2 Vertical wetting front with respect to time.

The wetting front profile was measured exactly below the dripper position by means of measuring scale. The measurements were taken at 10 minutes interval until the rate of advance with respect to time became zero. Measurements were taken at the vertical section of the wetted soil volume downward.

3.5 Distribution efficiency

The efficiency of any drip system is determined by the uniformity of water distribution by the emitters. The drip distribution efficiency is highly correlated to the discharge rates, number and spacing of emitters on laterals etc. It is also influenced by the nature of flow pattern from a single emitter.

The distribution efficiency was calculated by using the formula.

$$E_d = (1 - \bar{y}/\bar{d}) \times 100$$

Where E_d - Water distribution efficiency (%)

$\bar{d}$ - Average depth of water stored during irrigation, cm/meter depth of soil

$\bar{y}$ - Average numerical deviation from $\bar{d}$

The average depth of water stored during irrigation ($\bar{d}$) was calculated by using the formula

$$\bar{d} = (MC_2 - MC_1) \times \text{depth}/100 \times \text{bulk density}$$

Where, MC_2- Moisture content observed after irrigation

MC_1- Moisture content before irrigation

3.6 Soil moisture distribution pattern

The moisture extracted by the crop at different soil depths was determined by measuring the soil moisture at regular intervals and in horizontal plane at several depths within the root zone. From the moisture content data in the root zone, soil moisture distribution within the root zone was obtained. This provides the basis for determining the exact discharge rate and number of emitters.

Soil moisture content measurements were taken before and after irrigation. Since coconut is having active root absorption zone between 0.75 to 1.25 m away from the bole, the observations were taken at 45,90 and 105cm horizontal distances from the emitter in the root zone i.e., up to 205m from the bole . The measurements were taken at different depths of 15,30 60 and 75 cms in every treatment before irrigation, 1 hour and 24 hour after irrigation. Soil moisture measurements were done by the gravimetric method since it is the most accurate one. Soil samples were taken from desired depths and horizontal distances using tube type soil augers. After taking soil samples, they were kept in moisture boxes and covered immediately with lids. The samples were weighed along with moisture box (W_2) and then placed in an oven at 105^0c for 24 hours until all the moisture was driven off. It was weighed again and the weight (W3) was noted. Soil moisture content is expressed as percent by weight on dry basis.

Moisture content was calculated by using the formula

$$\text{Moisture Content}(\%) = \frac{(W_2 - W_3) \times 100}{(W_3 - W_1)}$$

Where W_1 - Weight of empty container with lid (g)

W_2 - Weight of container with lid and moist soil (g)

W_3 - Weight of container with lid and dry soil (g)

Soil moisture distribution pattern was drawn by noting the moisture content values before and after irrigation.

3.7 Analysis of data

Statistical analysis of the data obtained was done using the computer package systat 8.0. Analysis of variance was done by using Generalised linear model to find out the significant difference in the observations with respect to treatments. The level of significance used was p=0.05 .The mean distribution efficiency of different treatments at different depths (horizontal planes) and time were found.

Results and Discussion

RESULTS AND DISCUSSION

The data obtained from field test were analysed to provide the basic information of soil moisture movement under drip irrigation. The results of the field study conducted are discussed in this chapter.

4.1 Soil properties

4.1.1 Soil texture

The results of soil textural analysis are shown in Appendices I & II. The results of the mechanical analysis (both sieve and sedimentation) were plotted to get particle size distribution curve. In this curve, percentage finer 'N' is taken as the ordinate and particle diameter(mm) as the abscissa on logarithmic scale. The resulting curve shown in Fig.4 reveals that the soil sample consists of 69.11 % sand 12% silt and 16% clay. As per USDA classification the textural class of the soil is sandy loam.

4.1.2 Bulk density

The bulk density of the soil was measured as in 3.2.2. The weight and volume of core cutter and weight of soil samples are given in table 2. The mean bulk density of the soil is found to be 1.82g/ cm^3. The bulk density of sandy loam soil ranges between 1.5 to 1.8 g/cm^3. The mean bulk density obtained for the soil is within this range.

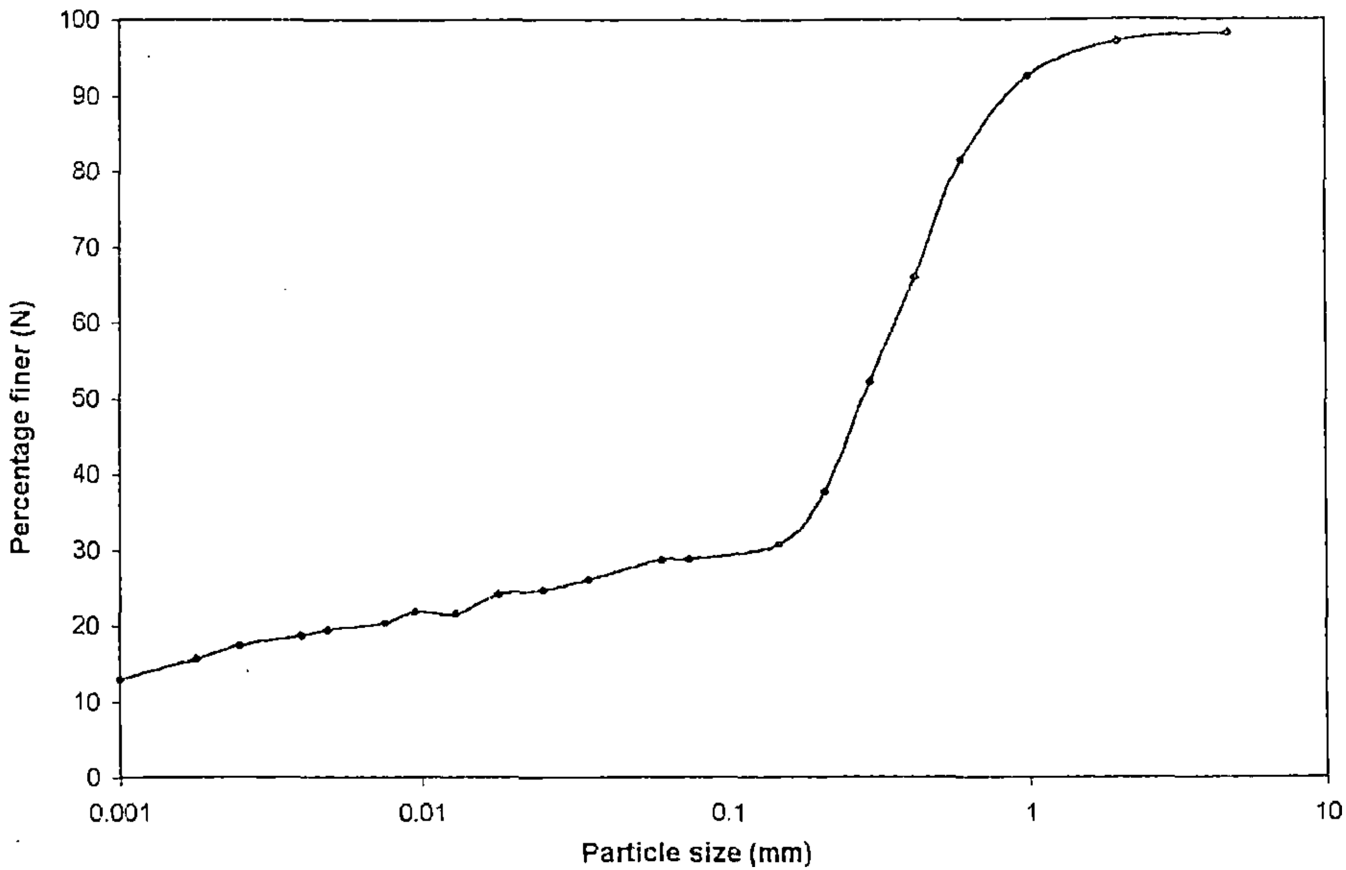


Fig. 4 Particle size distribution curve

Table 2 Determination of bulk density by core cutter method

Particulars	I	II	III
Weight of core cutter + dry soil, W_1(g)	1486.7	1426.4	1441.2
Weight of core cutter, W_2(g)	816	816	816
Weight of dry soil, W_3(g)	670.7	610.4	625.12
Volume of core cutter, V_1(cm^3)	348.42	348.42	348.42
Bulk density ,ρ(g/cm^3)=W_3/ V_1	1.92	1.75	1.79

The average bulk density of soil = 1.82 g/cm^3

4.1.3 Field Capacity

Observation on moisture content were taken from two locations at different soil depths from 13 hours onwards after saturation.. The graphs showing the moisture content against time for different soil depths are given in Fig.5 to 8.

These curves show that moisture content decreases with increase in time and finally reaches a constant value. Field capacity at 0-15, 15-30, 30-60 and 60-75 cm from ground surface were found out and are 10%, 12.6%, 12.2%, and 12% respectively. It was found that soil reached field capacity at 24 hours after saturation at each location. For sandy loam soil standard value of field capacity ranges between 3 to 15%. The field capacity values corresponding to different depths obtained in this study are within this range.

4.1.4 Infiltration rate

Cylinder infiltrometer test was conducted at 3 locations in the experimental field and the results are given in table 3

The curve showing the variation of average infiltration rate with elapsed time is shown in Fig.9. The curve indicates that infiltration rate decreases with increase in time and finally reaches a constant value. This constant value is termed as infiltration capacity or basic infiltration rate of the soil. As water moves into deeper layers, hydraulic gradient decreases and thereby infiltration rate also decreases. The functional relationship between accumulated infiltration(Y) and elapsed time(t) is represented by the empirical equation.

$$Y = at^{\alpha} + b$$ where

a , α and b are constants.

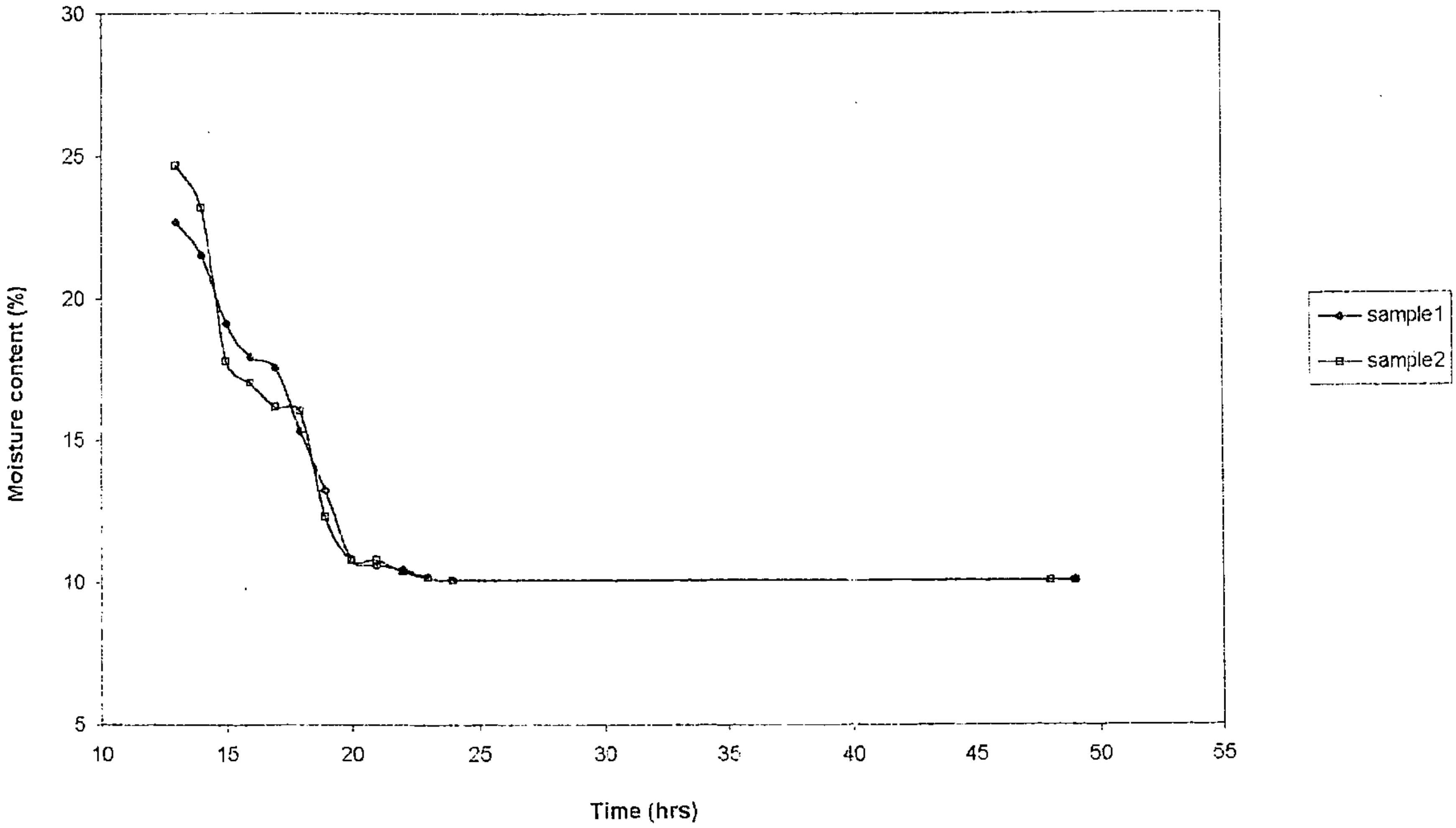


Fig. 5 Field capacity at 0-15 cm depth

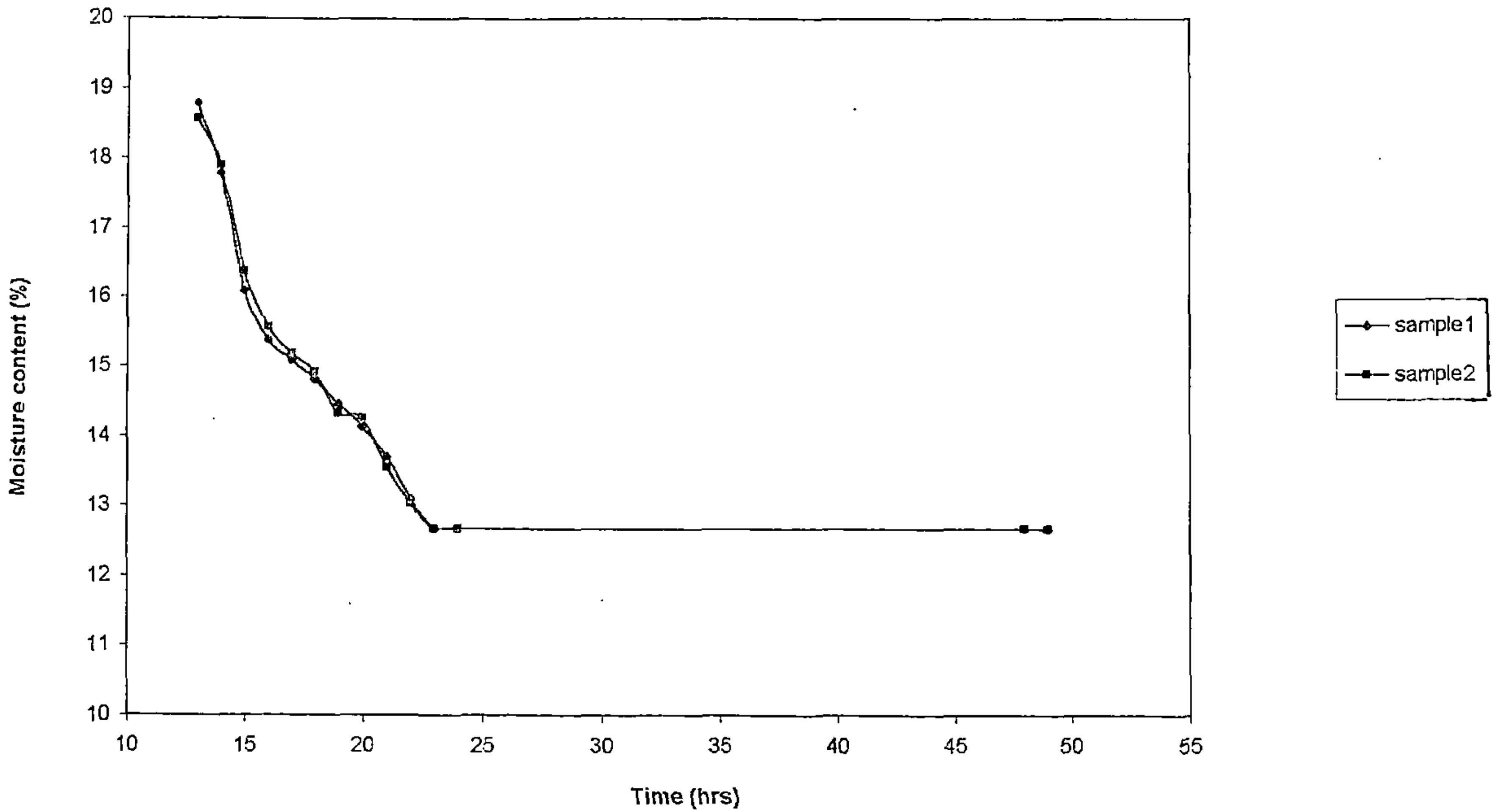


Fig. 6 Field capacity at 15-30 cm depth

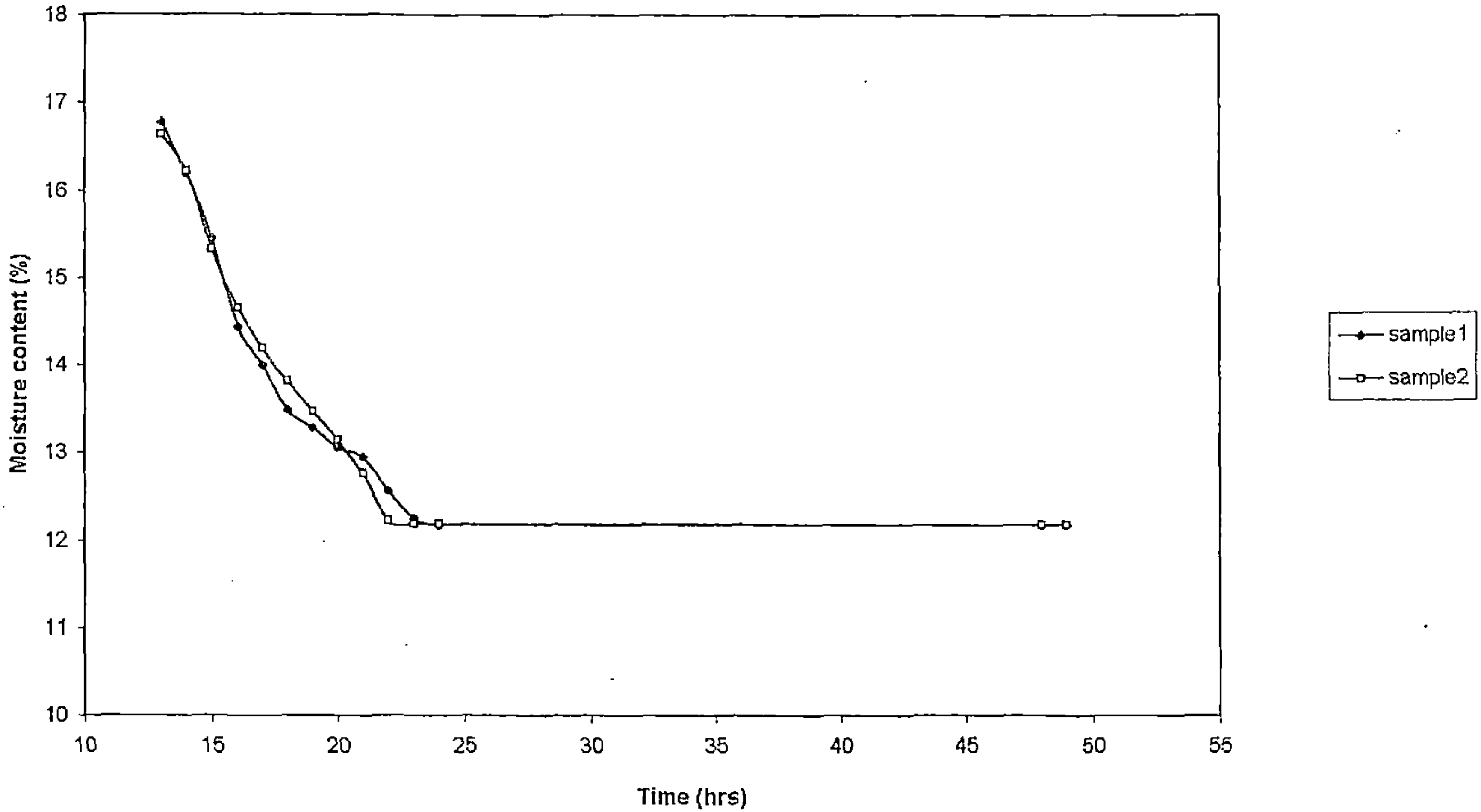


Fig. 7 Field capacity at 30-60 cm depth

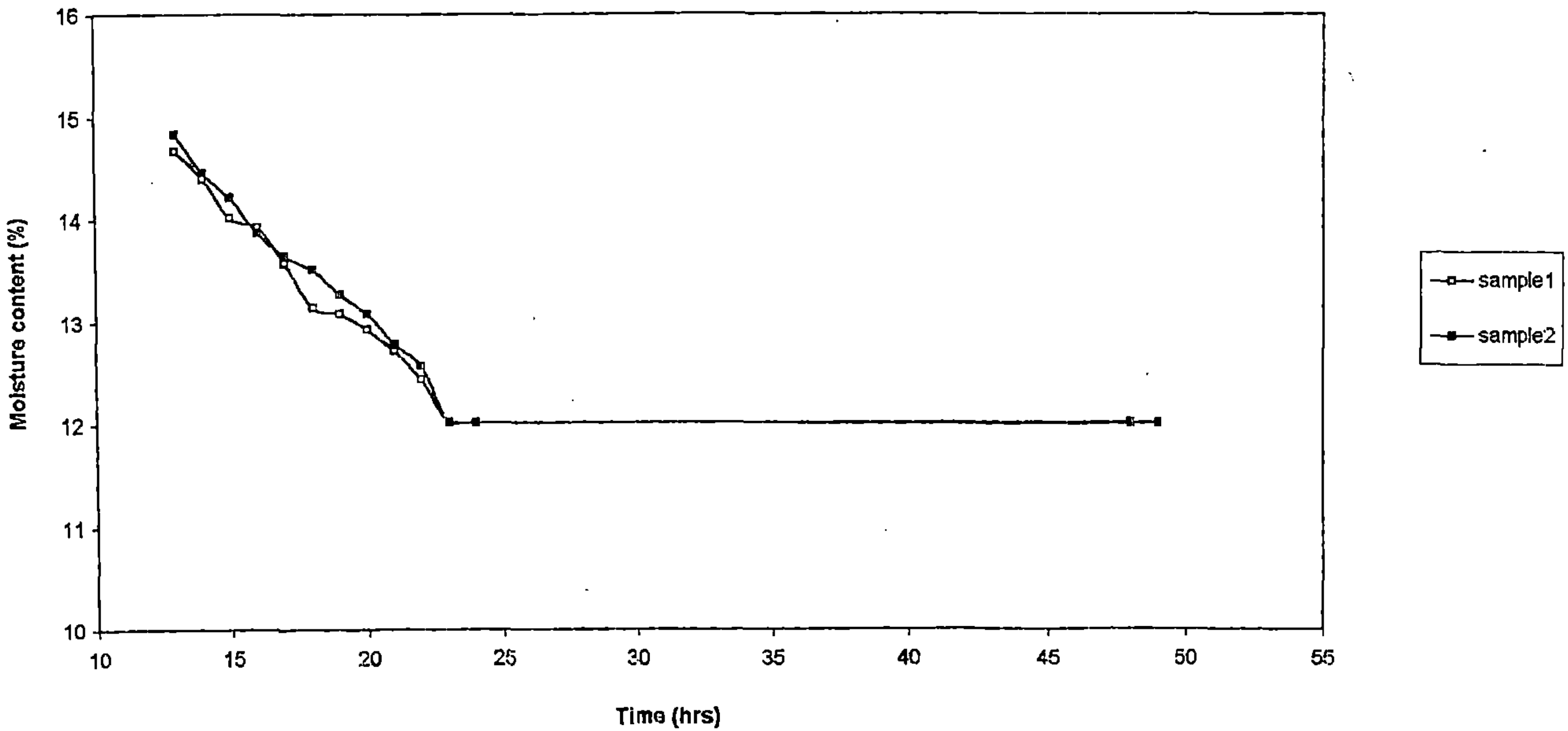


Fig. 8 Field capacity at 60-75 cm depth

Table 3 RESULTS OF INFILTRATION STUDIES

Elapsed time (min.)	Cylinder No.1					Cylinder No.2					Cylinder No.3					Average infiltration rate (cm/hr)	Average accumulated infiltration (cm)
	Distance of water surface from reference point			Infiltration during period		Distance of water surface from reference point			Infiltration during period		Distance of water surface from reference point			Infiltration during period			
	Initial Depth (cm)	Final Depth (cm)	Decrease in water level (cm)	Average rate cm/hr	Accumulated infiltration (cm)	Initial Depth (cm)	Final Depth (cm)	Decrease in water level (cm)	Average rate cm/hr	Accumulated infiltration (cm)	Initial Depth (cm)	Final Depth (cm)	Decrease in water level (cm)	Average rate cm/hr	Accumulated infiltration (cm)		
-	11.0	-	-	-	-	11.0	-	-	-	-	11.0	-	-	-	-	-	-
5	11.0	9.3	1.7	20.4	1.7	11.0	9.4	1.6	19.2	1.6	11.0	9.3	1.7	20.4	1.7	20.4	1.7
10	11.0	9.5	1.5	18	3.2	11.0	9.48	1.52	18.24	3.12	11.0	9.47	1.53	18.36	3.23	18.2	3.18
15	11.0	10.1	0.9	10.8	4.1	11.0	10.03	0.97	11.64	4.09	11.0	10.06	0.94	11.28	4.17	11.24	4.12
25	11.0	9.5	1.5	9.0	5.6	11.0	9.5	1.55	9.3	5.64	11.0	9.48	1.52	9.12	5.69	9.14	5.64
45	11.0	8.31	2.69	8.07	8.29	11.0	8.3	2.7	8.1	8.34	11.0	8.3	2.7	8.1	8.39	8.09	8.34
60	11.0	9.1	1.9	7.6	10.19	11.0	9.04	1.96	7.84	10.3	11.0	9.08	1.92	7.68	10.31	7.7	10.26
75	11.0	9.1	1.9	7.6	12.09	11.0	9.2	1.8	7.2	12.1	11.0	9.15	1.85	7.4	12.16	7.4	12.11
90	11.0	8.6	2.4	7.2	14.49	11.0	8.7	2.3	6.9	14.4	11.0	8.7	2.3	6.9	14.46	7.0	14.45
110	11.0	8.6	2.4	7.2	16.89	11.0	8.7	2.3	6.9	16.7	11.0	8.7	2.3	6.9	16.76	7.0	16.78
130	11.0	8.6	2.4	7.2	19.29	11.0	8.7	2.3	6.9	19.0	11.0	8.7	2.3	6.9	19.06	7.0	19.12

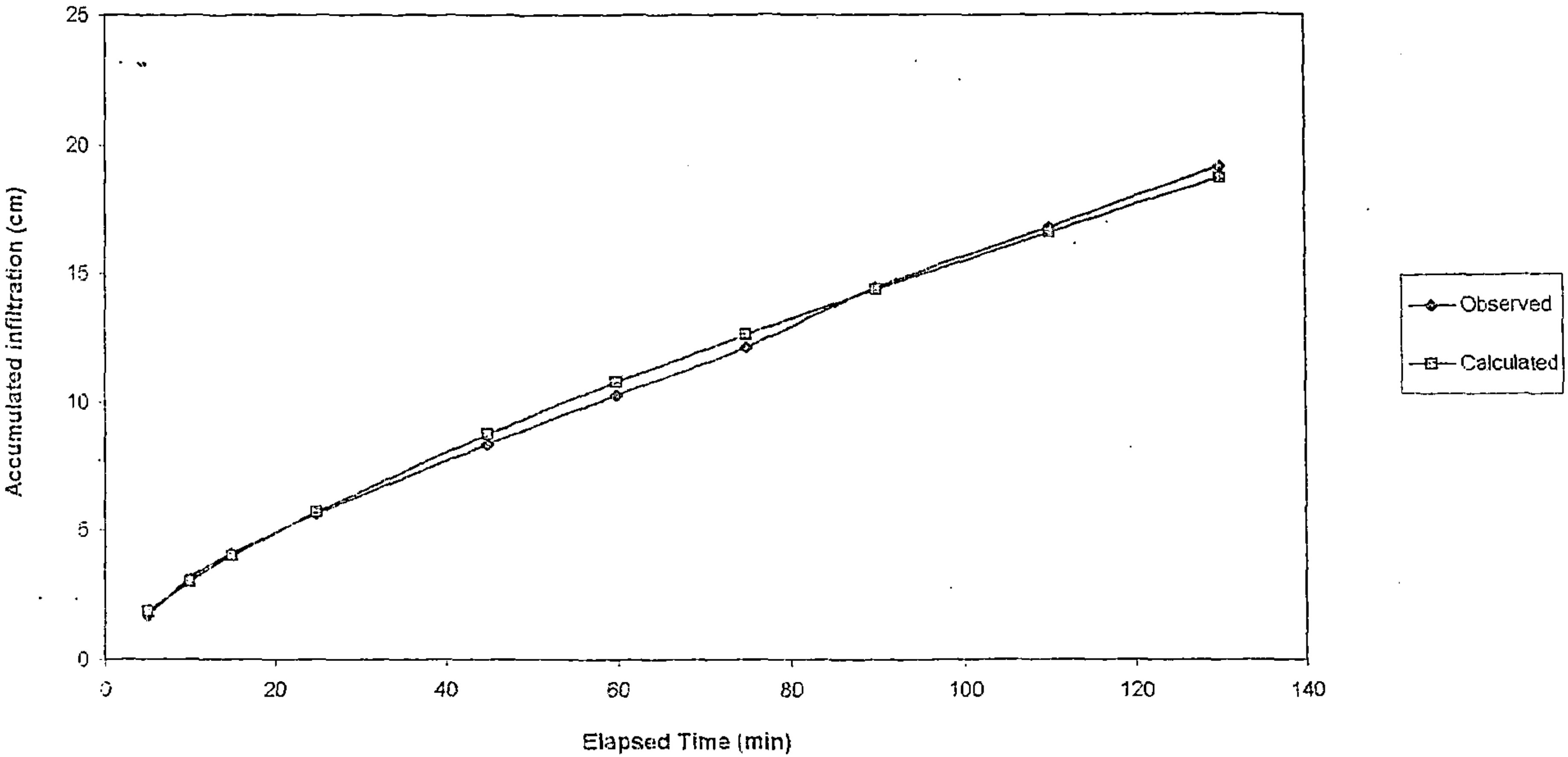


Fig. 10 Variation of accumulated infiltration with time

From the observations obtained in this test the value of a, α and b are determined by the method of averages and is shown in the Appendix III. Then the functional relationship connecting the infiltration rate and time is given by

$$Y = 0.56\, t^{0.72} + 0.11$$

Variation of observed and calculated accumulated infiltration rates with time are shown in Fig. 10. From the curves it is seen that variation between observed and calculated values of accumulated infiltration is less. The basic infiltration rate of sandy loam soil ranges between 6.5 to 12.5 cm/h. The average basic infiltration rate obtained for the soil is within this range.

4.1.5 Permanent wilting point

After the complete wilting of the plants in each can, soil samples were collected and the moisture content on percentage basis were calculated. The wilting point moisture content values are shown in table 4.

The average wilting point of the soil is 4.152 %. For sandy loam soil, the standard value of permanent wilting percentage ranges between 3 to 8%. The average wilting point of the soil obtained is within this range.

4.1.6 Saturated Hydraulic Conductivity

Quantity of flow were observed at a particular time interval (10 minutes) for three samples and results are given in tables 5 to 10. The coefficient of permeability or saturated hydraulic conductivity values calculated for different depths (0-12, 12-24, 24-36, 36-48, 48-60, 60-72) are also shown in tables 5 to 10.

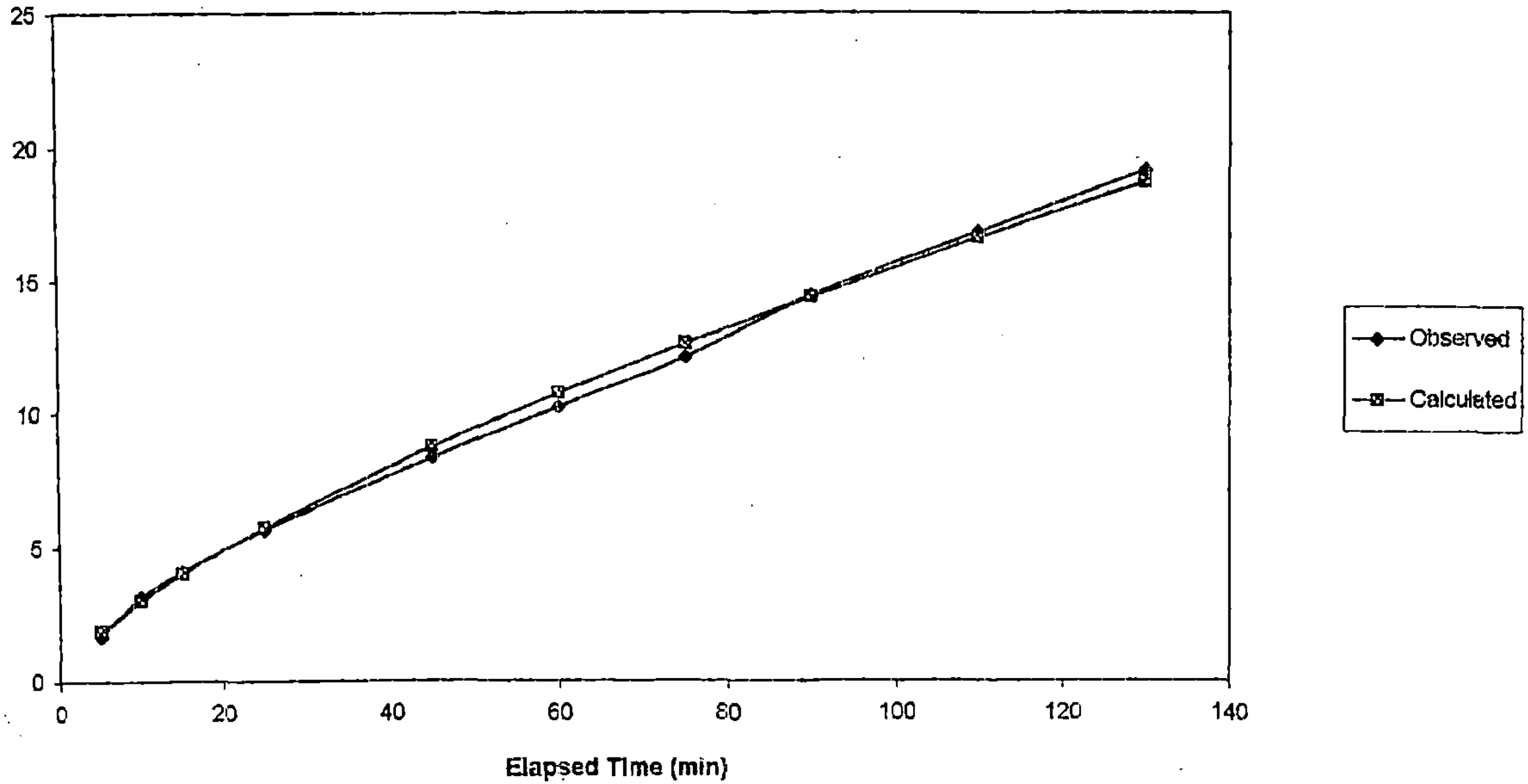


Fig. 10 Variation of accumulated infiltration rate with time

Table 4 Moisture content(%) observed at wilting point for the soil

Can No.	Weight of wet soil(g)	Weight of dry soil(g)	Moisture Content (%)
1	12	11.5	4.16
2	12.5	12.0	4.0
3	11.8	11.3	4.23
4	10.6	10.2	3.77
5	12.9	12.0	4.6

Average moisture content(%) = 4.152

Table 5 Determination of coefficient of permeability by constant head permeability test for 0-12 cm depth

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	227	232	236
	II	229	225	220
	III	226	220	228
Average flow		227	225.66	228
Coefficient of permeability(cm/sec)		1.99×10^{-3}	1.97×10^{-3}	1.99×10^{-3}

The average value of coefficient of permeability for 0-12 cm depth was 1.98×10^{3} cm/sec

Table 6 Determination of coefficient of permeability by constant head permeability test for 12-24 cm depth

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	213	210	211
	II	217	207	216
	III	215	215	212.33
Average flow		227	210.66	228
Coefficient of permeability(cm/sec)		1.88×10^{-3}	1.84×10^{-3}	1.86×10^{-3}

The average value of coefficient of permeability for 12-24 cm depth was 1.86×10^{-3} cm/sec

Table 7 Determination of coefficient of permeability by constant head permeability test for 24-36 cm depth

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	203	196	197
	II	199	188	192
	III	197	206	189
Average flow		200	197.66	192
Coefficient of permeability(cm/sec)		1.75×10^{-3}	1.73×10^{-3}	1.68×10^{-3}

The average value of coefficient of permeability for 24-36 cm depth was 1.72×10^{-3} cm/sec

Table 8 Determination of coefficient of permeability by constant head permeability test for 36-48 cm depth.

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	195	182	193
	II	186	197	196
	III	185	186	187
Average flow		189	183.33	192
Coefficient of permeability(cm/sec)		1.65×10^{-3}	1.65×10^{-3}	1.68×10^{-3}

The average value of coefficient of permeability for 36-48cm depth was 1.66×10^{-3} cm/sec

Table 9 Determination of coefficient of permeability by constant head Permeability test for 48-60 cm depth

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	170	173	191
	II	186	189	184
	III	177	182	176
	Average flow	178	181.33	183.66
Coefficient of permeability(cm/sec)		1.56×10^{-3}	1.59×10^{-3}	1.61×10^{-3}

The average value of coefficient of permeability for 48-60 cm depth was 1.58×10^{-3} cm/sec

Table 10 Determination of coefficient of permeability by constant head permeability test for 60-72 cm depth

		Sample I	Sample II	Sample III
Hydraulic head, h(cm)		6	6	6
Length of sample , L(cm)		12	12	12
Hydraulic gradient		0.5	0.5	0.5
Cross-sectional area of sample (cm^2)		95.03	95.03	95.03
Time interval(sec)		600	600	600
Quantity of flow(cm^3)	I	150	163	167
	II	168	168	158
	III	170	166	153
	Average flow	162	165.66	159.0
Coefficient of permeability(cm/sec)		1.48×10^{-3}	1.45×10^{-3}	1.39×10^{-3}

The average coefficient of permeability or saturated hydraulic conductivity for 60-72 cm depth was 1.44×10^{-3} cm/sec

From tables 5 to 10 it is seen that the hydraulic conductivity decreases with increase in depth i.e, from 0-12 cm depth to 60-72 cm depth. This may be due to the effect of entrapped air bubbles. Even after saturation, it is not possible to replace all the air by water and some of the air is trapped in the pores. This trapped air bubbles obstruct the flow of water. These changes in air content decrease the hydraulic conductivity. In deeper layers the problem of air entrapment is noticeable. So as the depth increases hydraulic conductivity decreases.

4.2 Irrigation requirement for the coconut palm

Irrigation is an essential requirement for achieving higher crop production. Several studies indicated that the coconut palms respond very well to irrigation depending on the quantity and quality of water applied ,soil type, climatic conditions and initial soil moisture level. Crop evapotranspiration (ET crop), also known as consumptive use is determined by the climatic environment and specific crop characteristics. The crop evapotranspiration (ET crop) is the product of reference crop evapotranspiration (ETo) and crop coefficient (Kc) . The value of Kc depends on the growth stage of the crop and for a mature coconut palm is about 0.75. ETo was calculated by using pan evaporation method.

$$ETo = Epan \times Pan\ coefficient$$

Since there was no rainfall during the study period, water requirement of the palm itself is taken as the irrigation requirement. The quantity and duration of irrigation required for each treatment per palm was calculated based on the observed pan evaporation values of the previous day (day before irrigation).

The pan evaporation (Epan) data recorded during the study period is given in Appendix IV. The observed values of pan evaporation were found to be comparatively more than the value recorded in the previous studies. This may due to the instrumental error. From the table shown in Appendix IV, it can be seen that as an average, pan evaporation was found to be increase uniformly from March to May. Water requirement of one coconut palm was calculated by multiplying the crop evapo-transpiration (ETcrop) with area of the basin to be irrigated.

The quantity of water applied to each palm per day through different treatments and the duration of irrigation required for each treatment are shown in table 11

4.3 Mechanics of soil moisture advance from point source

4.3.1 Advance of Ponded Zone

The curves showing the variation of ponded zone with time for both discharges (4lph & 8 lph) are shown in Fig. 11. From the figure it can be seen that in case of 4 lph emitter, the ponded zone radius with respect to time for 10 to 20 minutes interval is lesser than that for 20 to 30 minutes. The variation of ponded zone radius with respect to time becomes zero at 30 minute (i.e. ponded zone radius attains a constant value). In the case of 8 lph emitter, the variation of ponded zone radius with respect to time for 20 to 30 minutes is more compared to that for 10 to 20 and 30 to 50 minutes duration. The ponded zone radius attains a constant value only at 50 minute. In both cases high variation of ponded zone radius is found at 20 to 30 minutes interval compared to other time intervals. From the figure it is clear that ponded zone radius corresponding to 8 lph emitter is always more than that for 4 lph emitter. Ponded zone occurs when discharge rate exceeds infiltration rate of soil. Hence when the discharge rate increases ponded zone also increases.

4.3.2 Soil Moisture Profile

The soil moisture profile at various time intervals for 4 lph emitter is shown in Fig. 12. From the curves, it can be seen that in all the cases the maximum horizontal wetting radius was found at the ground surface. The rate of change in horizontal and vertical variation of wetting radius with time was in an abrupt manner upto 80 minutes. After that rate of change of wetting radius was found to decreases with time. At any particular time, the vertical wetting radius was found to decrease with horizontal distance. This decrease was found to increase with increase in time. The horizontal wetting radius attains a constant value at the ground surface at 120 minute and it was found to be 53.5 cm. The vertical wetting

Table 11. Quantity of water and the duration of irrigation required for each treatment.

Day	Treatment	Quantity of water applied (lit/day)	Duration of Irrigation (hrs)
12/3/99	T_3	53.43	3.34
15/3/99	T_3	53.43	3.34
18/3/99	T_3	53.43	3.34
21/3/99	T_4	54.5	1.7
24/3/99	T_4	54.5	1.7
27/3/99	T_4	55.03	1.71
30/3/99	T_1	55.57	4.63
2/4/99	T_1	55.57	4.63
5/4/99	T_1	56.10	4.675
8/4/99	T_2	56.64	2.36
11/4/99	T_2	56.64	2.36
14/4/99	T_2	56.1	2.33
17/4/99	T_5	57.17	2.38
20/4/99	T_5	57.17	2.38
23/4/99	T_5	57.7	2.4
26/4/99	T_6	57.17	1.19
29/4/99	T_6	57.17	1.19
2/5/99	T_6	57.17	1.19

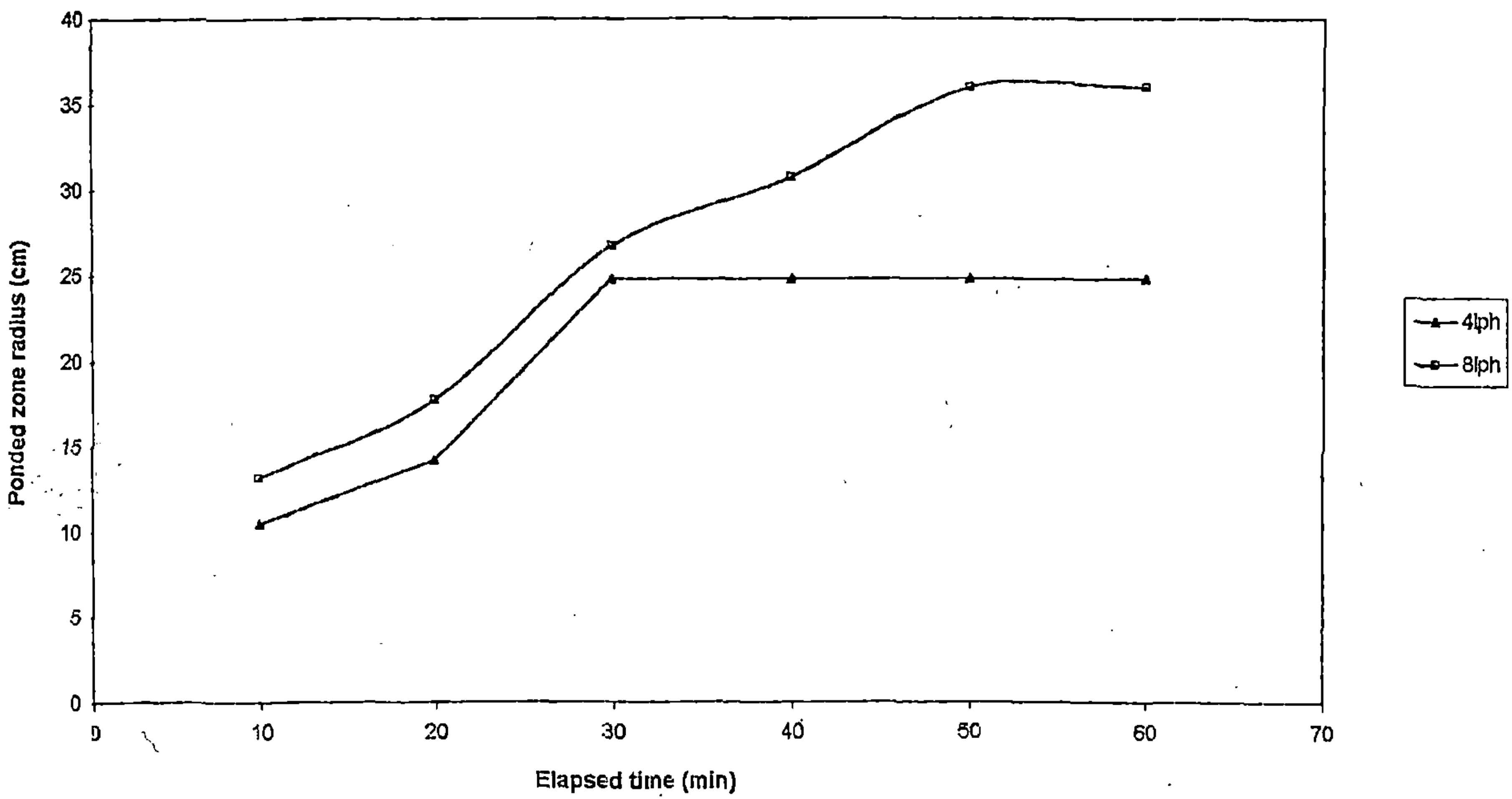


Fig. 11 Variation of ponded zone with time

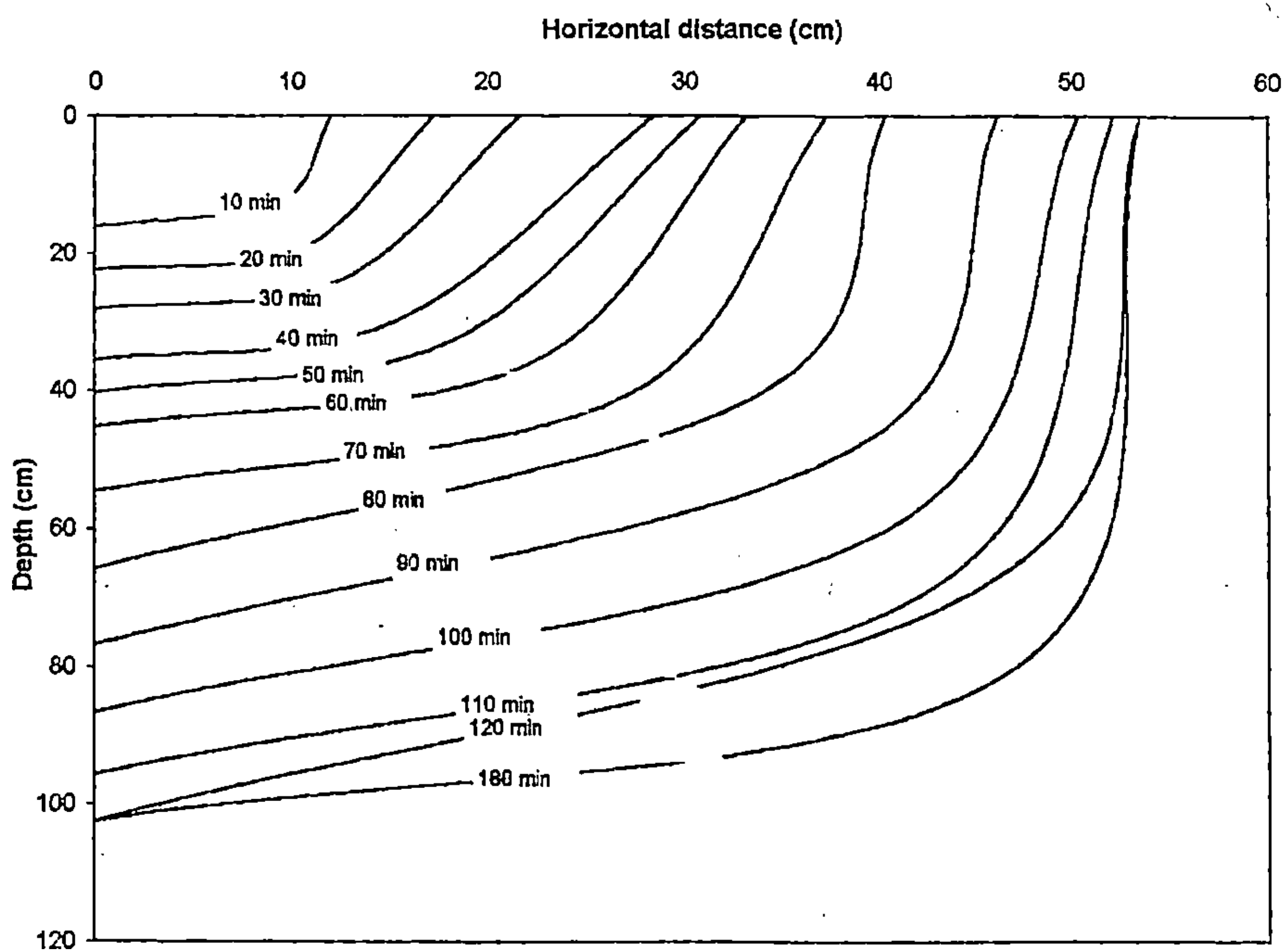


Fig. 12 Soil moisture profile for 4 lph emitter at various time intervals

radius attains a constant value below the emitter at 120 minutes and it was found to be 102.3cm.

The soil moisture profile at various time intervals for 8 lph emitter is shown in fig. 13. The curves reveal that maximum horizontal wetting radius was found at the surface up to 50 minute. After 50 minute horizontal wetting radius increases with increase in vertical distance. This increase in horizontal wetting radius with vertical distance was found to decrease with time. Initially, for a particular time, the vertical wetting radius was found to decrease with horizontal distance. This decrease in vertical wetting radius with horizontal distance decreases with in crease in time and the vertical wetting radius attains a uniform value at 30 minute. After that vertical wetting radius was found to increase with horizontal distance up to 70 minute. From 70 to 110 minute it found to decrease with time and again from 120 to 180 minute it increases with time. The rate of change of horizontal and vertical wetting radius with time was found negligible at 180 minute. The maximum horizontal wetting radius at the surface attains a constant value of 80 cm at 180 minute and vertical wetting radius below the emitter attains a constant value of 120 cm at 180 minute.

From this it can be seen that movement of water in the vertical direction is faster than horizontal direction. This may be due to sandy loam texture of the soil, i.e, in this soil type vertical infiltration is more than the lateral infiltration. Evidently, it shows that gravitational force plays a greater role in the distribution of soil moisture in sandy loam soil.

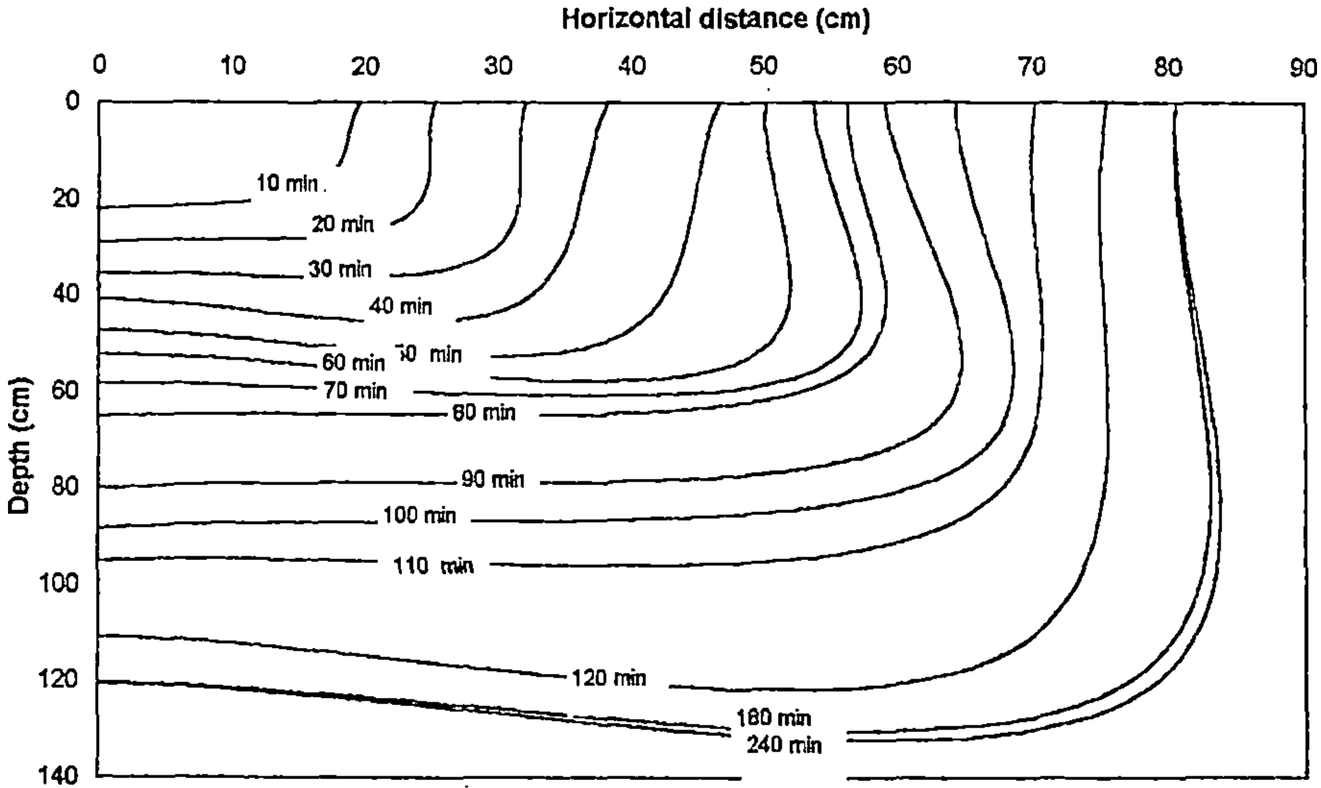


Fig.13 soil moisture profile for 8lph emitter at various time intervals

4.3.3 Vertical advance of Soil moisture front

The vertical advance of soil moisture front was plotted against elapsed time on logarithmic scale for both the discharge rates and are shown in Fig. 14 & 15. The resulting straight line suggested a relationship between vertical advance of soil moisture front against elapsed time. The vertical advance of water with respect to time can be expressed by an exponential equation as given below

$$Y = AX^B$$

Where Y - Vertical wetted zone radius (cm)
X - Elapsed time(min)
A & B - Constants

Equations relating vertical advance(cm) and elapsed time (min) for both 4 lph and 8 lph emitters are given in Fig. 14 & 15. The values of vertical advance with respect to time were calculated using these equations and are plotted in the same Fig. 14&15. The coefficient of determination (R^2) of these equations were more than 0.95, indicating that there is no significant difference in observed and predicted values.

4.3.4 Horizontal advance of soil moisture front.

An equation of the form $Y = AX^2 + BX + C$ was fitted to horizontal advance of wetted zone front against elapsed time as

Where,

Y - Horizontal wetted zone radius(cm)

X - Elapsed time (min)

A,B,&C - Constants

Equation relating horizontal advance (cm) and elapsed time (min) for both 4 lph and 8lph emitters are given in Fig. 16 & 17. The values of horizontal advance with respect to time were calculated using these equations and are plotted in the same Fig. 16 & 17. The coefficient of determination (R^2) of these equations were

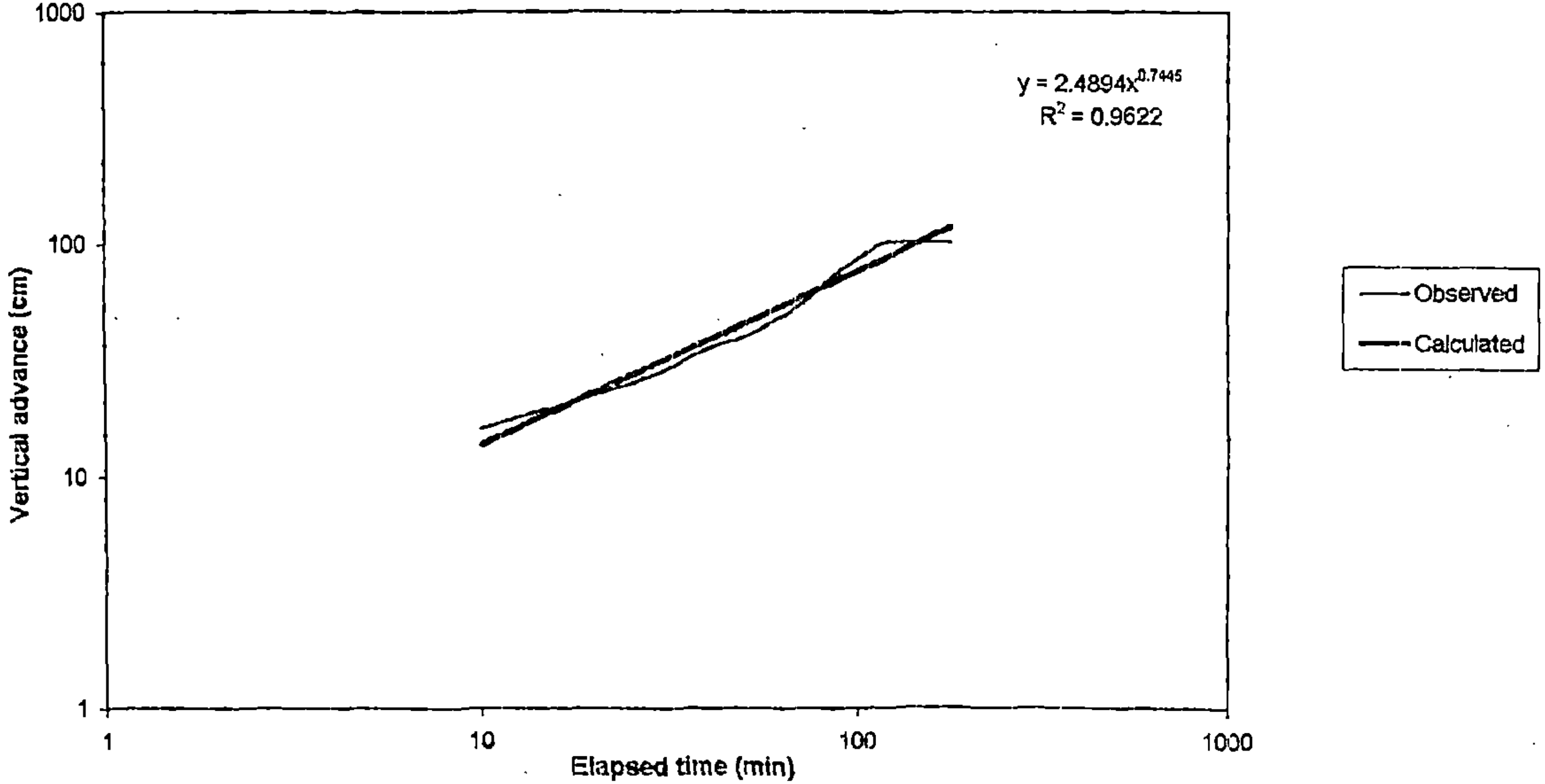


Fig. 14 Vertical advance of moisture front with time for 4lph emitter

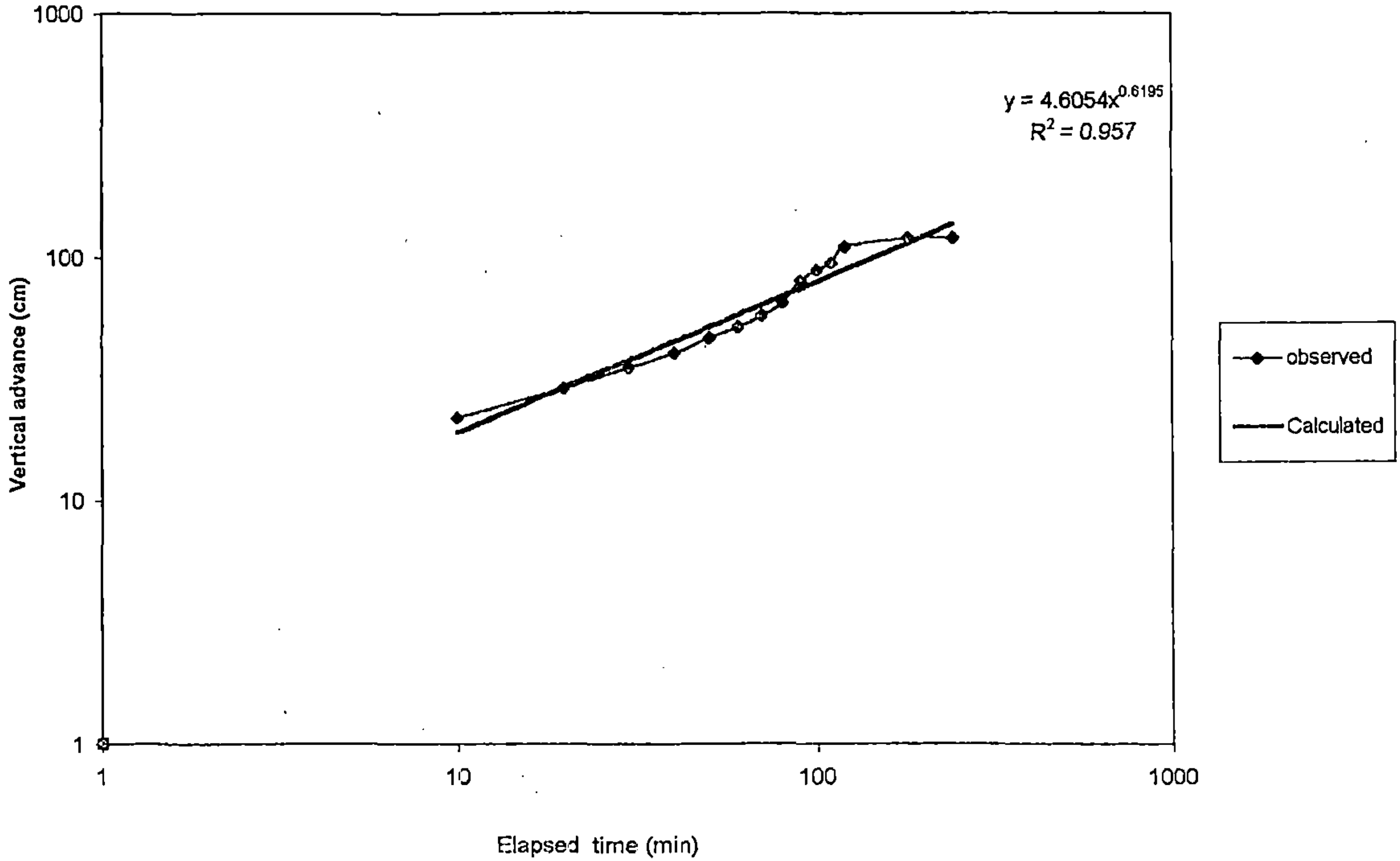


Fig. 15 Vertical advance of soil moisture front with time for 8lph emitter

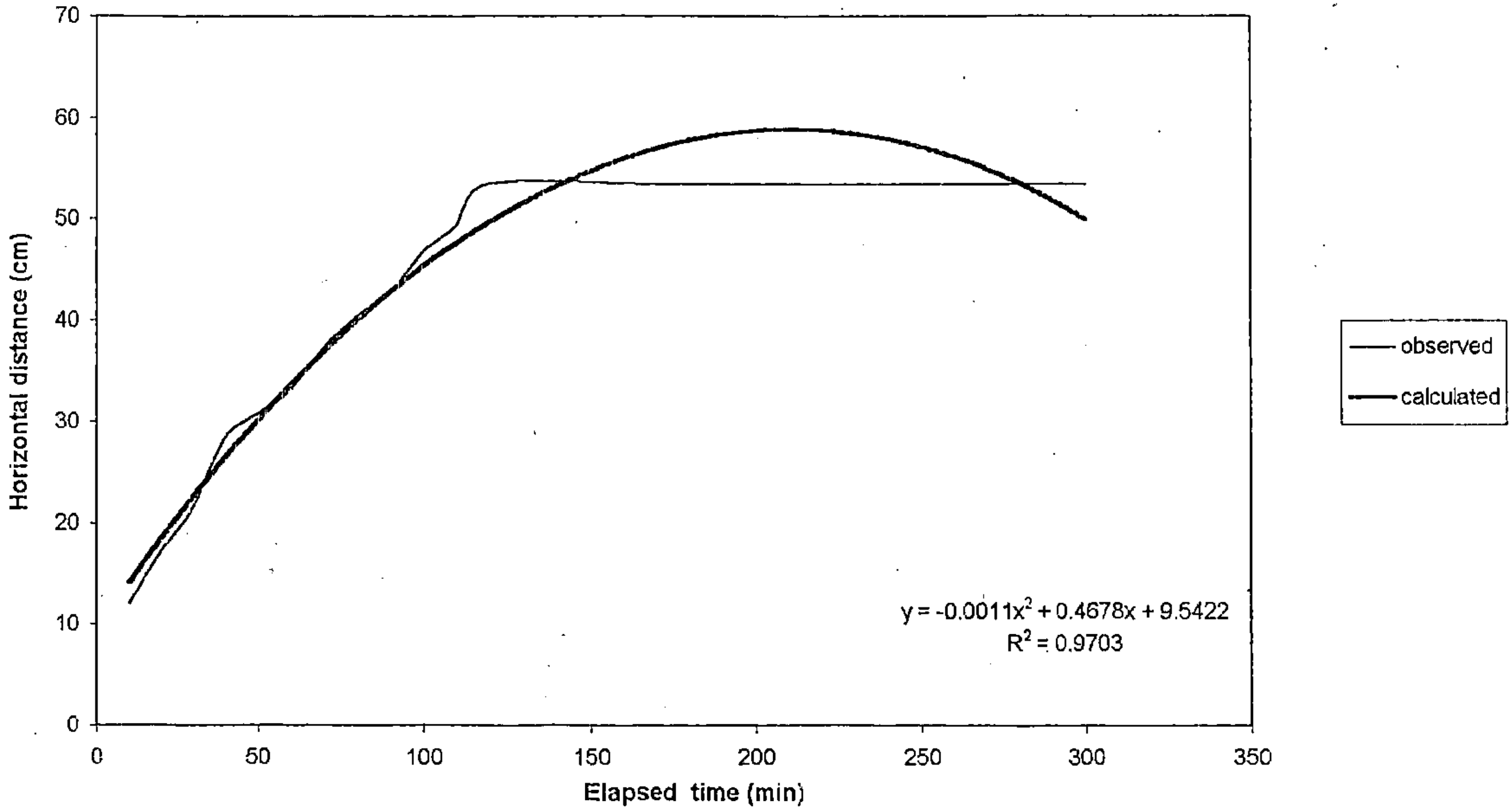


Fig. 16 Horizontal advance of soil moisture front with time for 4lph emitter

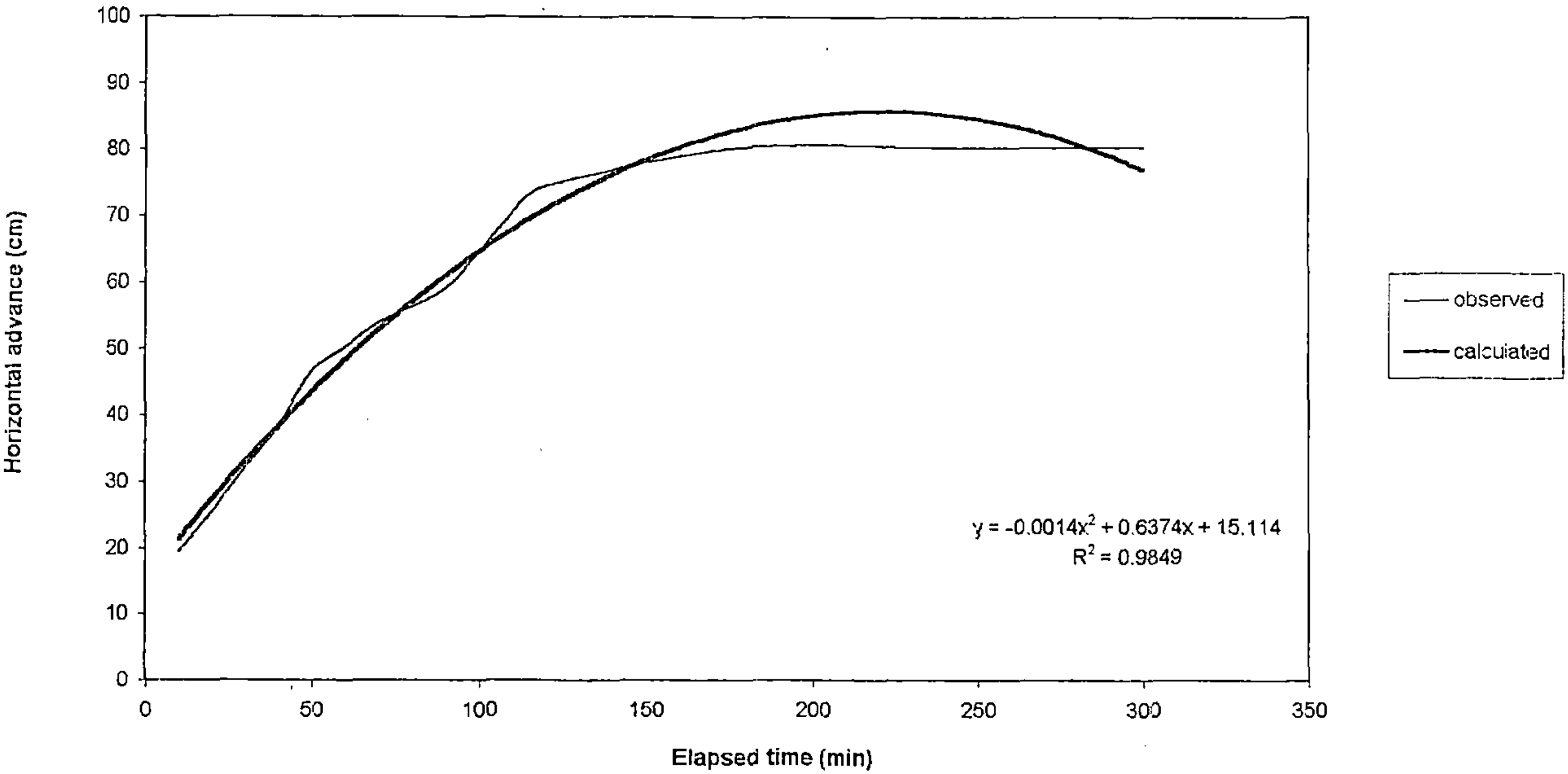


Fig. 17 Horizontal advance of soil moisture front with time for 8lph emitter

more than 0.95, indicating that there is no significant difference in observed and predicted values.

4.4 Soil moisture distribution pattern

The data obtained from the field study were analysed to understand the soil moisture distribution resulting form drip irrigation. The data were taken for three test series having four replications for each series. Experiments were conducted for different discharge rates (4 and 8lph) and varying number of emitters (3,4 and 6). The soil samples were collected from different depths and horizontal distances. Gravimetric method was used to evaluate the soil moisture regime in the crop root zone, which helps is monitoring the distribution of soil moisture as a function of depth as well as the horizontal distance from the point source (emitter) of water application. The data also provide information regarding the characteristics of soil moisture distribution from an emitter as a function of elapsed time at different water application rates.

The soil samples were taken from four different depths in the crop root zone i.e, 15,30, 60 and 75 cms and lateral distances of 45, 90 and 105 cms from the emitters. From all sets of test series, second set of data was selected for the analysis which shows better result. The analysis of the data of moisture content before irrigation, 1 hour after irrigation, 24 hour after irrigation and 3 days after irrigation was done and soil moisture contour maps were plotted by using computer software package 'Surfer' of windows version. The distribution efficiency was calculated for different depths of 15,30,60 and 75 cm for all treatments. The distribution efficiency was calculated by using the formula.

$$E_d = (1 - \bar{y}/\bar{d}) \times 100$$

Where E_d - Water distribution efficiency (%)

$\bar{d}$ - Average depth of water stored during irrigation, cm/meter depth of soil

$\bar{y}$ - Average numerical deviation from $\bar{d}$

The average depth of water stored during irrigation ($\bar{d}$) was calculated by using the formula

$\bar{d}$ = (MC_2-MC_1) x depth/100xbulk density

Where, MC_2- Moisture content observed after irrigation

MC_1- Moisture content before irrigation.

The efficiency values calculated at various depths for different treatments for 1 hour and 24 hours after irrigation are shown in table 12 and 13.

From the table 12, it can be seen that the efficiency is comparatively more at 15 and 30 cm depths than 60 and 75 cm depths. The reduction in efficiency at deeper layers is due to the less time available for the movement of moisture. At 15 cm depth the efficiency is slightly less compared to 30cm depth, due to highest rate of evaporation and percolation. The distribution efficiency for different treatments at various depths for 24 hours after irrigation is shown in table 13. From the table, it can be seen that for all the treatments the efficiency is comparatively more at 30 and 60 cm depths than 15 and 75 cm depths. This may be due to more uniform distribution of moisture. At 15 cm depth, which is more close to the surface layer due to highest rate of evaporation, percolation and uneven distribution of moisture, the distribution efficiency was found less compared to 30 and 60cm depths. At 75 cm depth distribution efficiency was very less compared to all other depths. This may be due to the large reduction in the infiltration rate, compared to other depths. Due to the reduction in infiltration rate amount of moisture content at various points in deeper layers will be less. The infiltration decreases due to the following reasons.

Table 12. Distribution efficiency for different treatment at various depths for 1 hour after irrigation

Depth	T_1	T_2	T_3	T_4	T_5	T_6
15	66.07	85.57	84.26	91.97	71.23	75.37
30	69.56	88.69	86.96	93.53	73.79	76.21
60	37.59	52.48	75.5	78.18	44.32	53.49
75	32.7	49.24	67.79	76.21	40.03	43.59

Table 13. Distribution efficiency for different treatment at various depths for 24 hours after irrigation

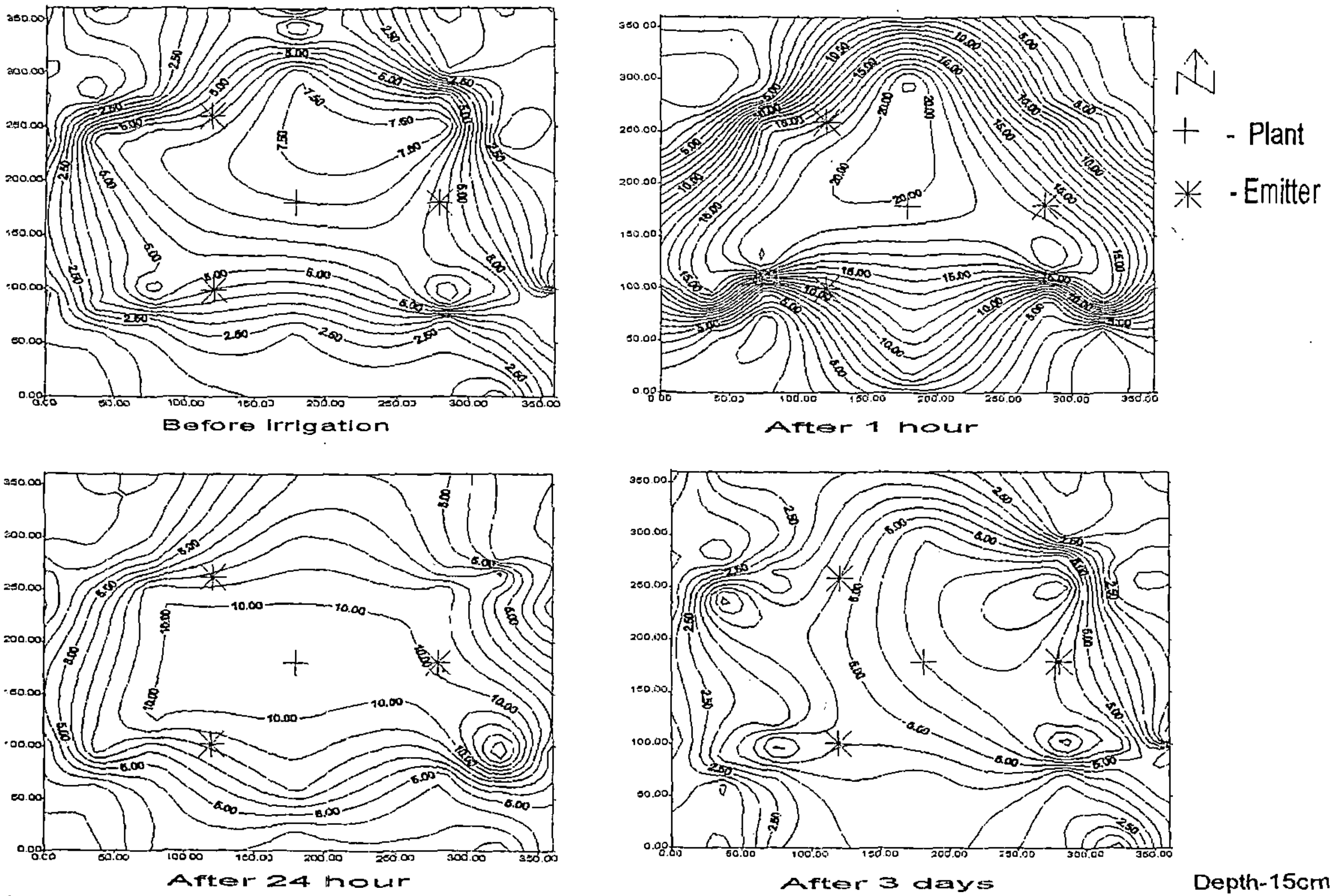
Depth	T_1	T_2	T_3	T_4	T_5	T_6
15	53.36	75.44	79.67	89.41	68.55	70.56
30	54.4	80.3	80.59	93.36	68.86	74.17
60	54.97	86.19	84.16	94.68	78.37	76.94
75	35.67	60.41	82.61	89.18	60.61	57.72

1) In most conditions the greatest rate of infiltration occurs when water contacts the soil surface since the capillary forces are strongest when the soil is driest. As water penetrates the soil to some depth the resistance to the forces acting on the water increases and the rate of infiltration decreases.
2) In order to occupy water in the pores of soil, air has to be replaced. When the depth increases and wetting is more, replacement of air become difficult. The air can be replaced only deep down. Hence infiltration rate decreases.
3) As depth increases hydraulic gradient reduces, since hydraulic gradient is the ratio of head to vertical distance. When depth increases, vertical distance increases & hydraulic gradient decreases. Hence infiltration rate also decreases.

Due to all these influences the rate of infiltration at various points varies widely as depth increases. Hence there is a wide variation in the moisture content at various points which results in the reduction of moisture distribution efficiency.

The soil moisture distribution pattern before irrigation, 1 hour, 24 hours, 3 days after irrigation for different treatments are shown in fig 18 to fig 41.

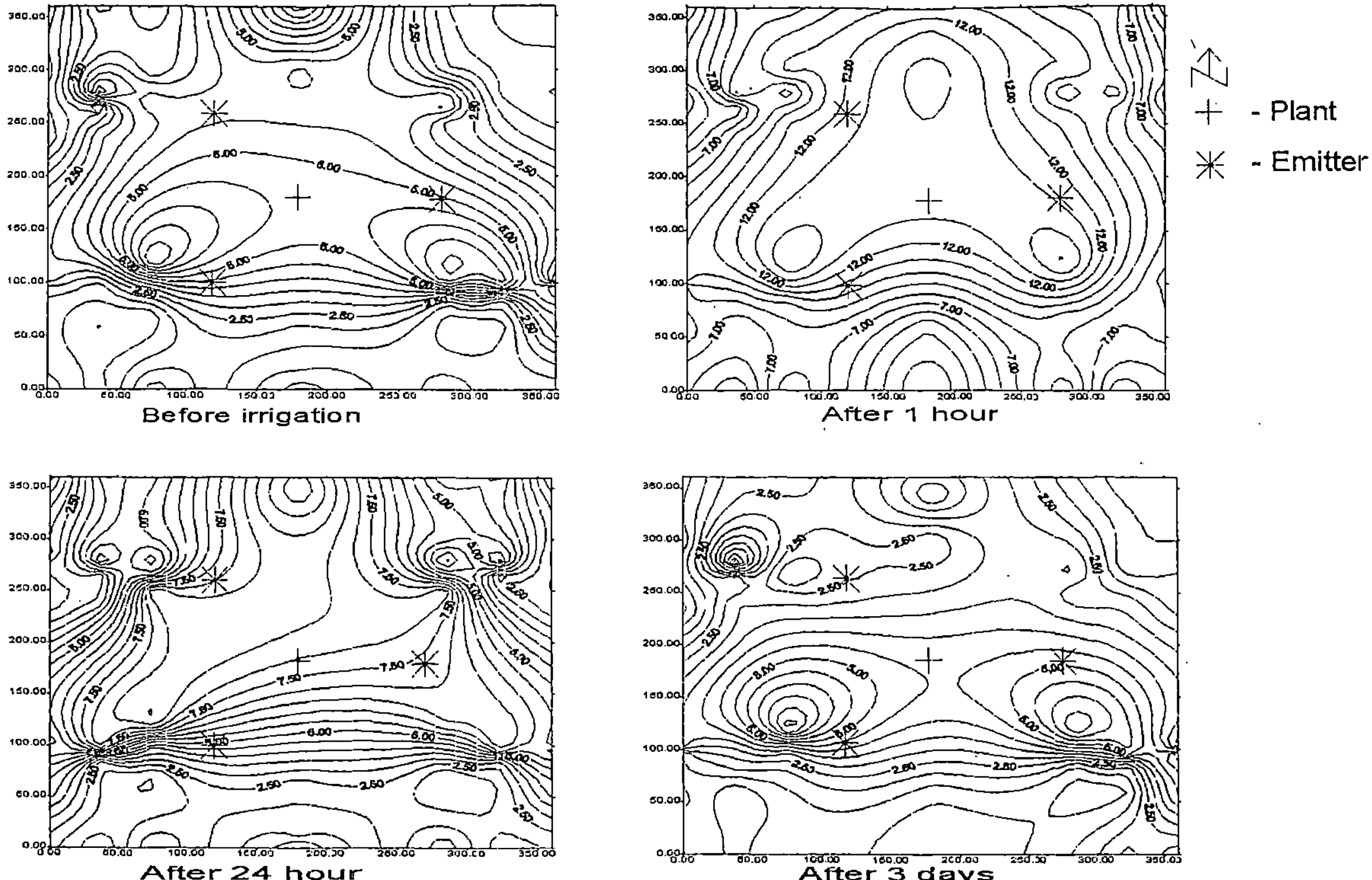
The soil moisture distribution pattern for different treatments (T_1, T_2, T_3, T_4, T_5 & T_6) revealed that, in each horizontal layer there is a distinct variation in the moisture content (%) from point to point at different time of observation, i.e, before irrigation, 1 hour, 24 hours and 3 days after irrigation. For a particular layer, the variation in the moisture content between the points is found to be more at 1 hour after irrigation. The time available for moving the moisture to the extreme point is not enough in this case. So the variation was more. In case of 24 hours and 3 days after irrigation, the time available for moving moisture to the extreme point are enough and the excess water (gravitational water) is drained to deeper layers. This may be the reason for less variation in moisture content after 24 hours and 3 days.



X-axis- Horizontal distance (cm)
Y-axis- Vertical distance (cm)
Z-axis- Moisture content (%)

Fig. 18 Soil moisture distribution pattern -T1

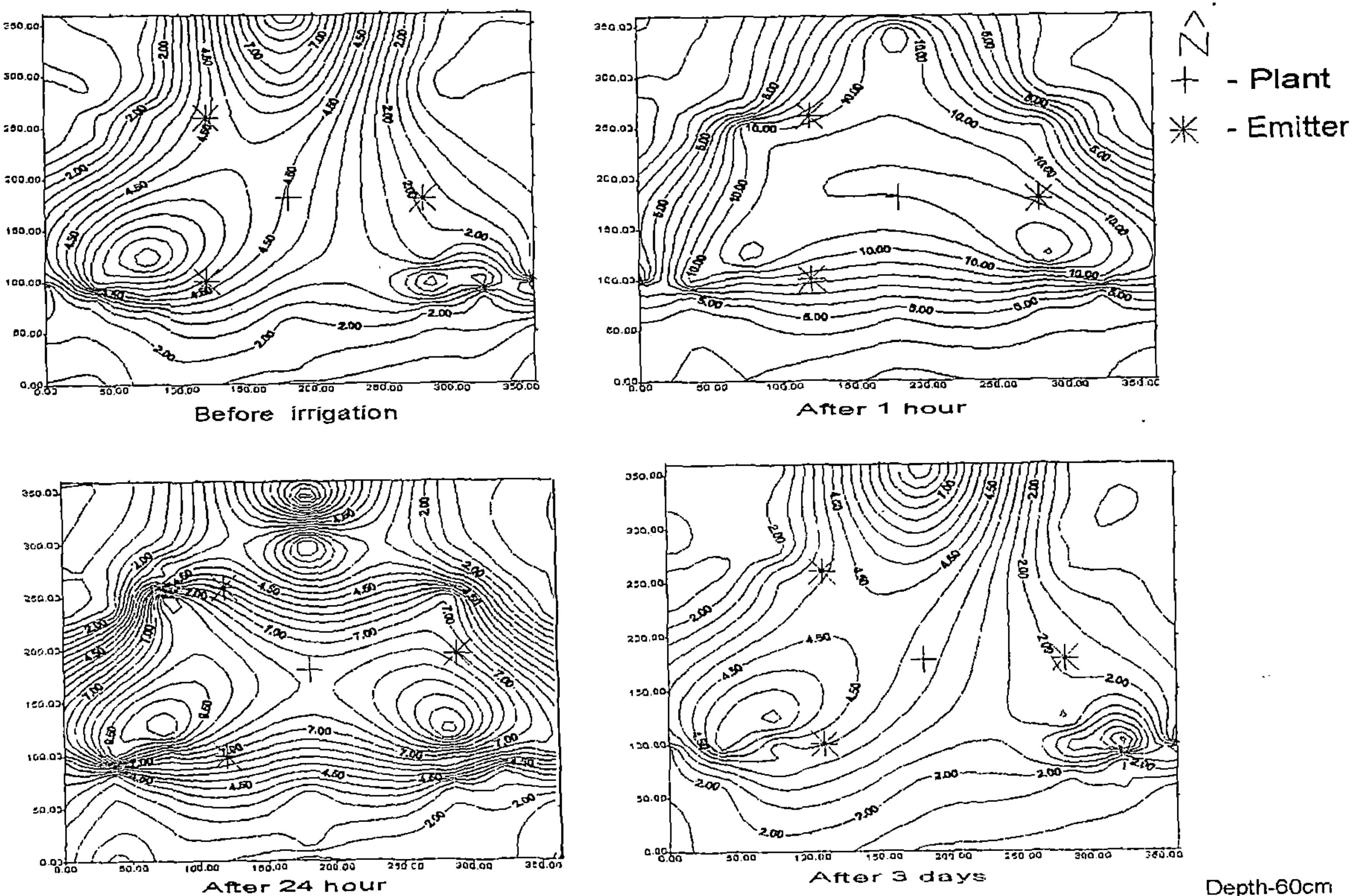
Depth-15cm
No. of emitters-3
Discharge-4lph
Grid size -50x50



X-axis- Horizontal distance (cm)
Y-axis- Vertical distance (cm)
Z-axis- Moisture content (%)

Fig. 19 Soil moisture distribution pattern -T1

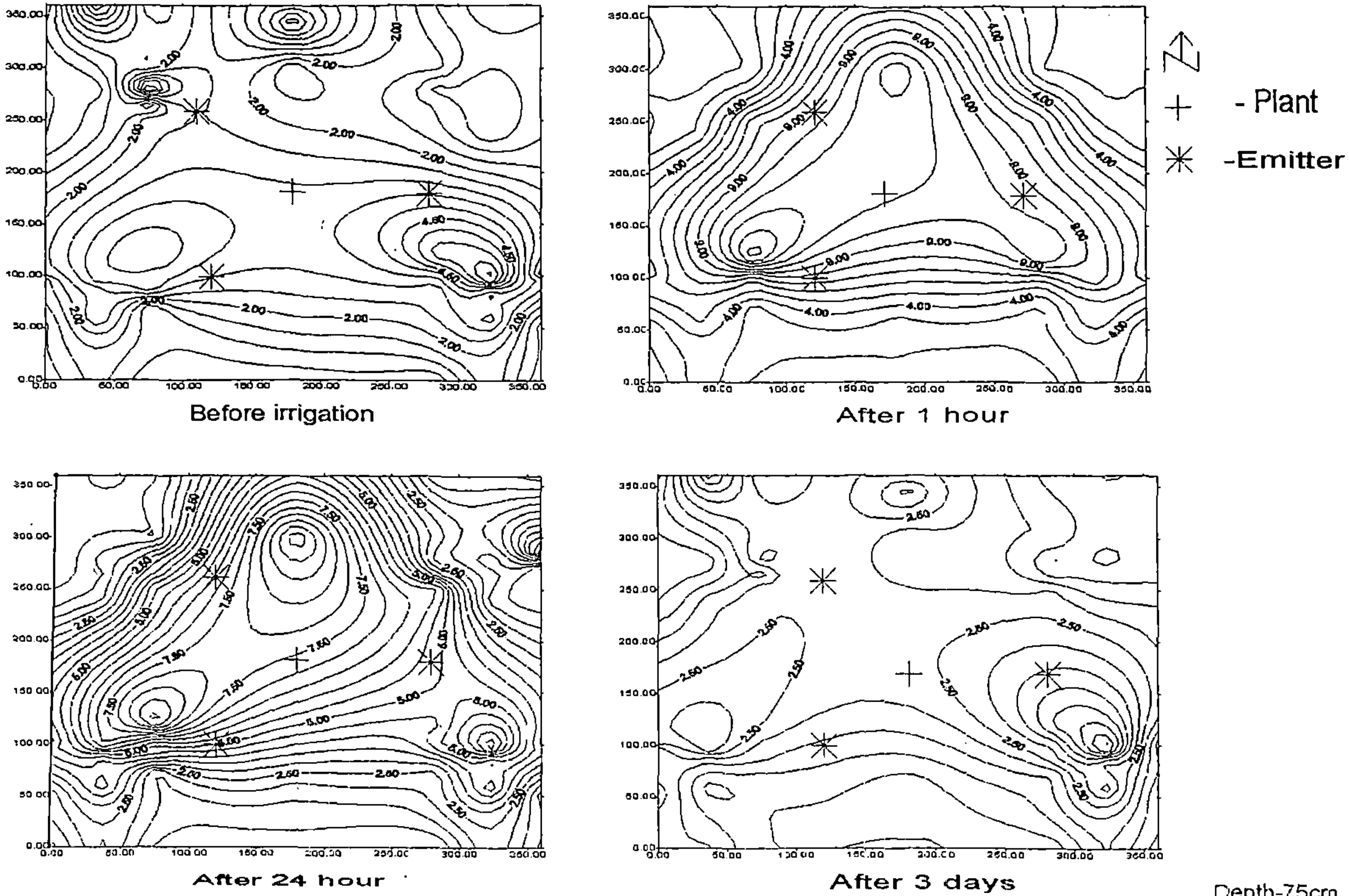
Depth-30cm
No. of emitters-3
Discharge -4lph
Grid size- 50x50



X-axis- Horizontal distance (cm)
Y-axis- Vertical distance (cm)
Z-axis- Moisture content (%)

Depth-60cm
No.of emitters-3
Discharge-4lph
Grid size - 50x5

Fig. 20 Soil moisture moisture distribution pattern-T1



X-axis- Horizontal distance (cm)
Y-axis- Vertical distance (cm)
Z-axis- Moisture content (%)

Fig. 21 Soil moisture distribution pattern -T1

Depth-75cm
No.of emitters
Discharge-4lp
Grid size -50x

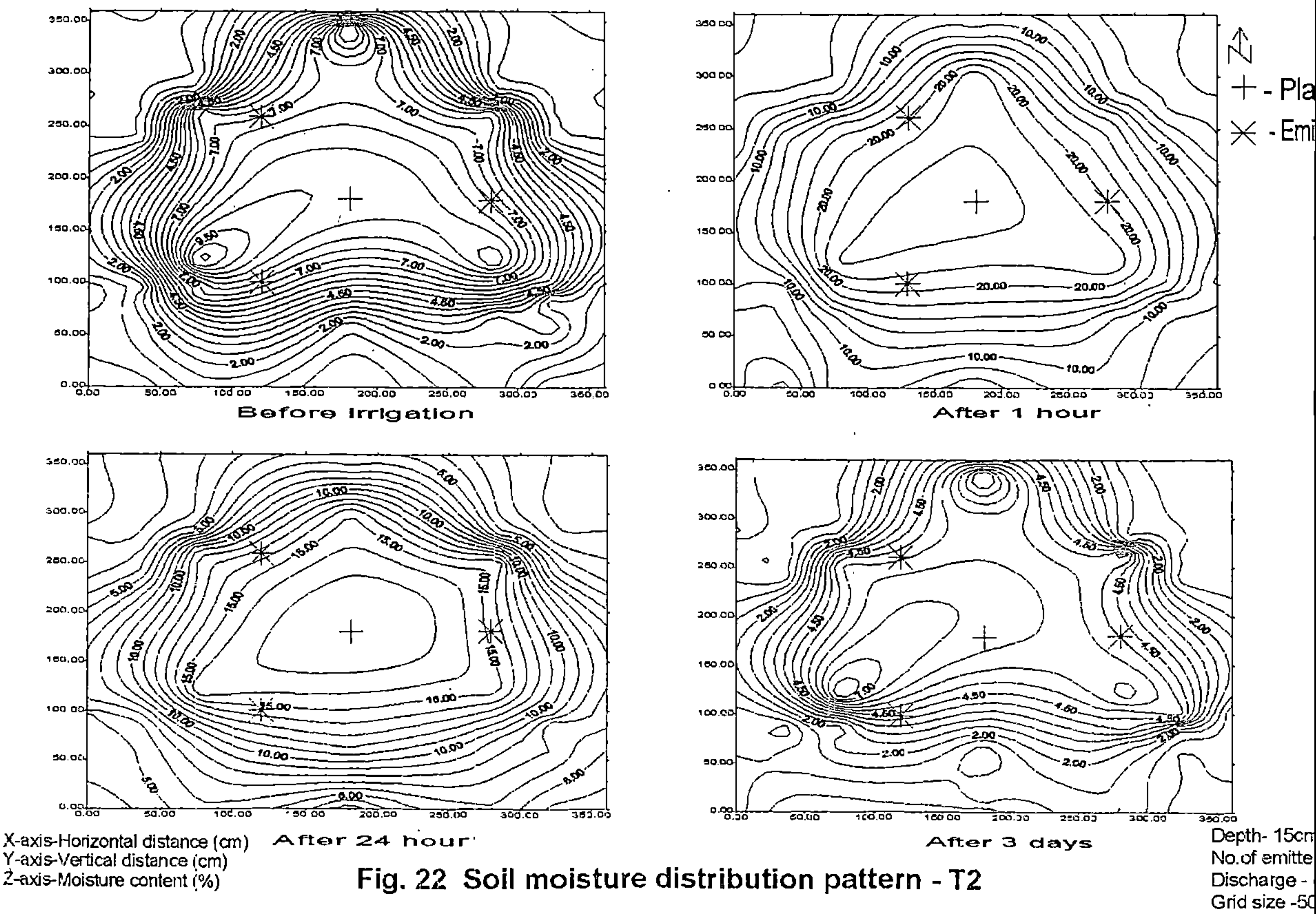
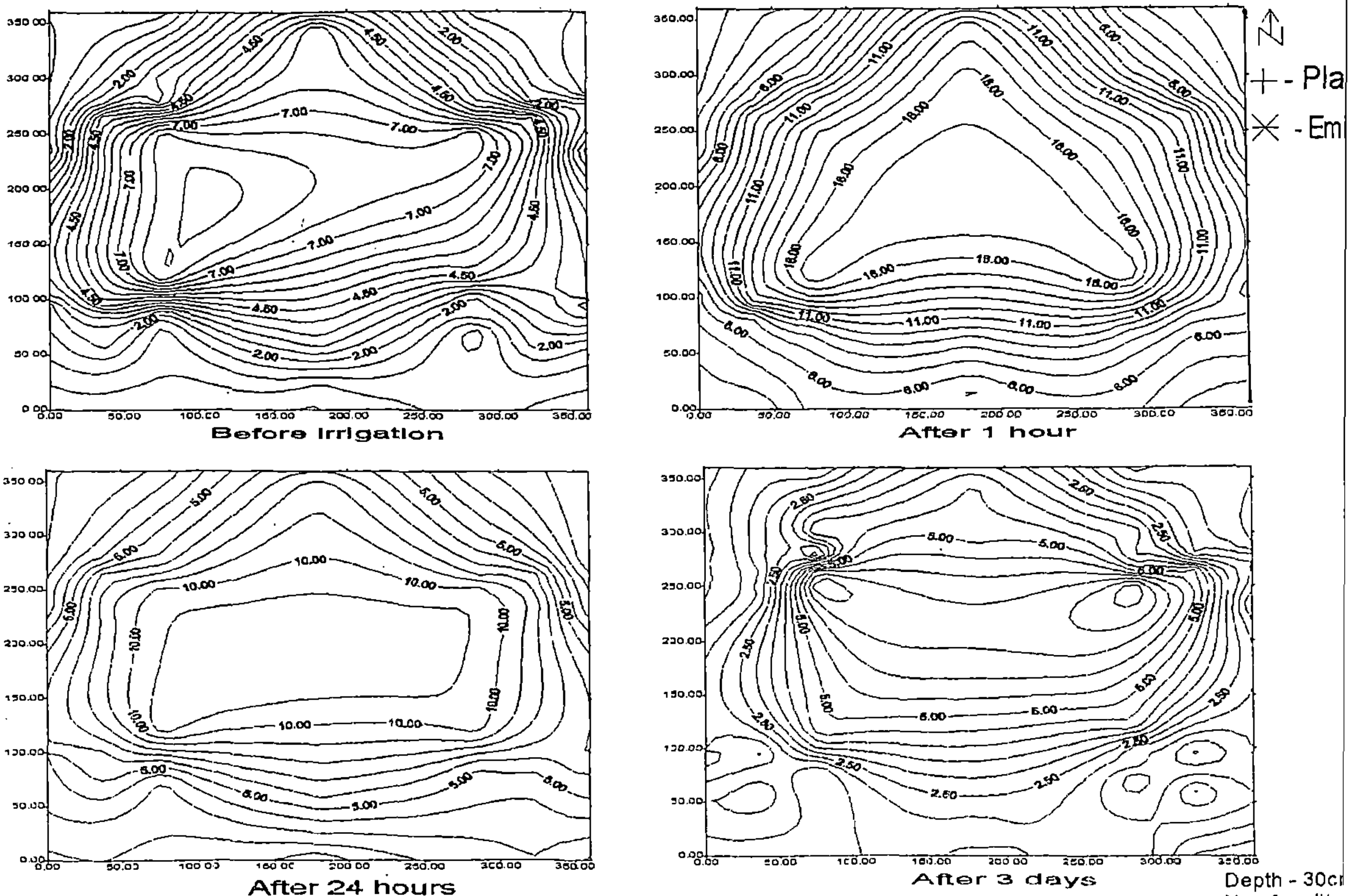


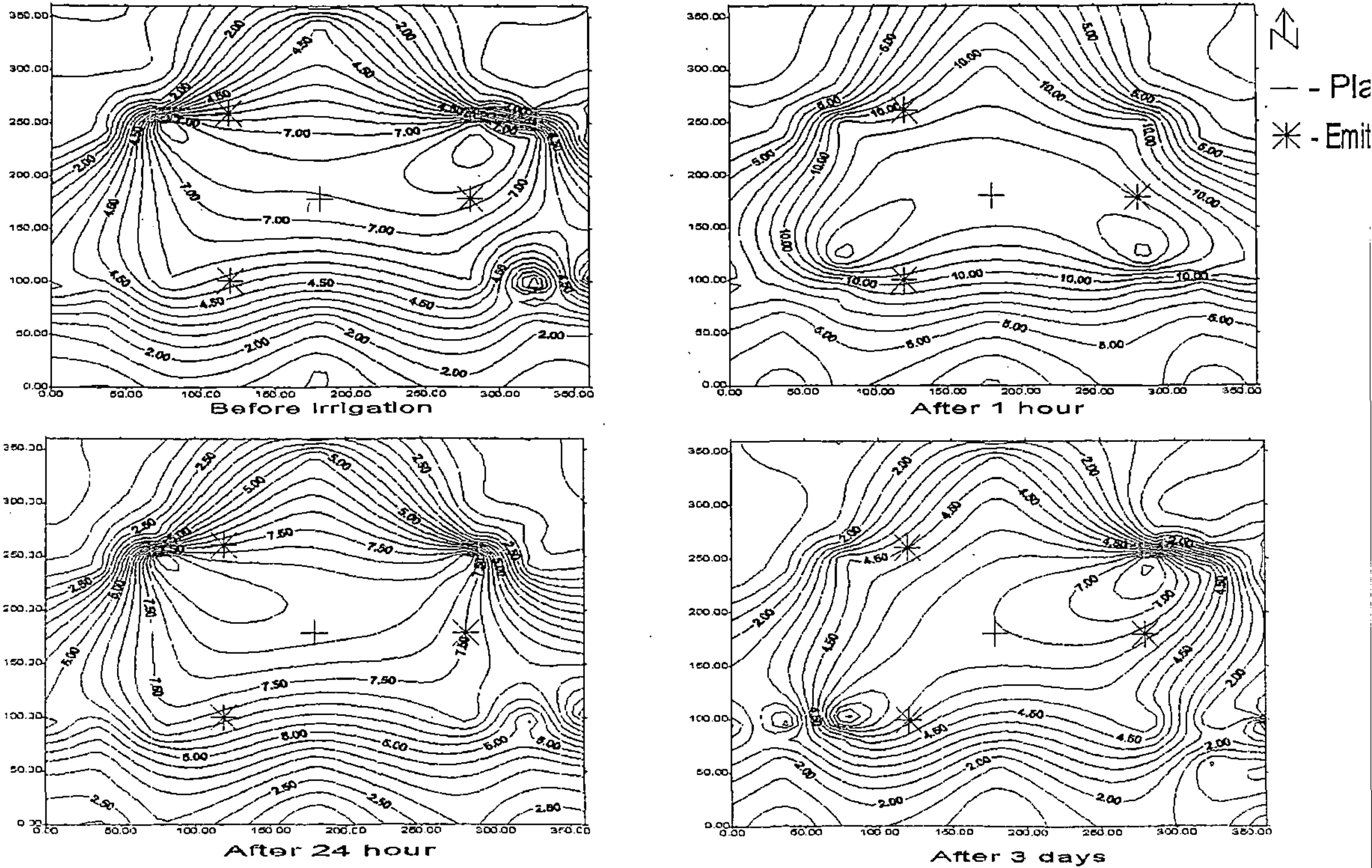
Fig. 22 Soil moisture distribution pattern - T2



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 23 Soil moisture distribution pattern- T2

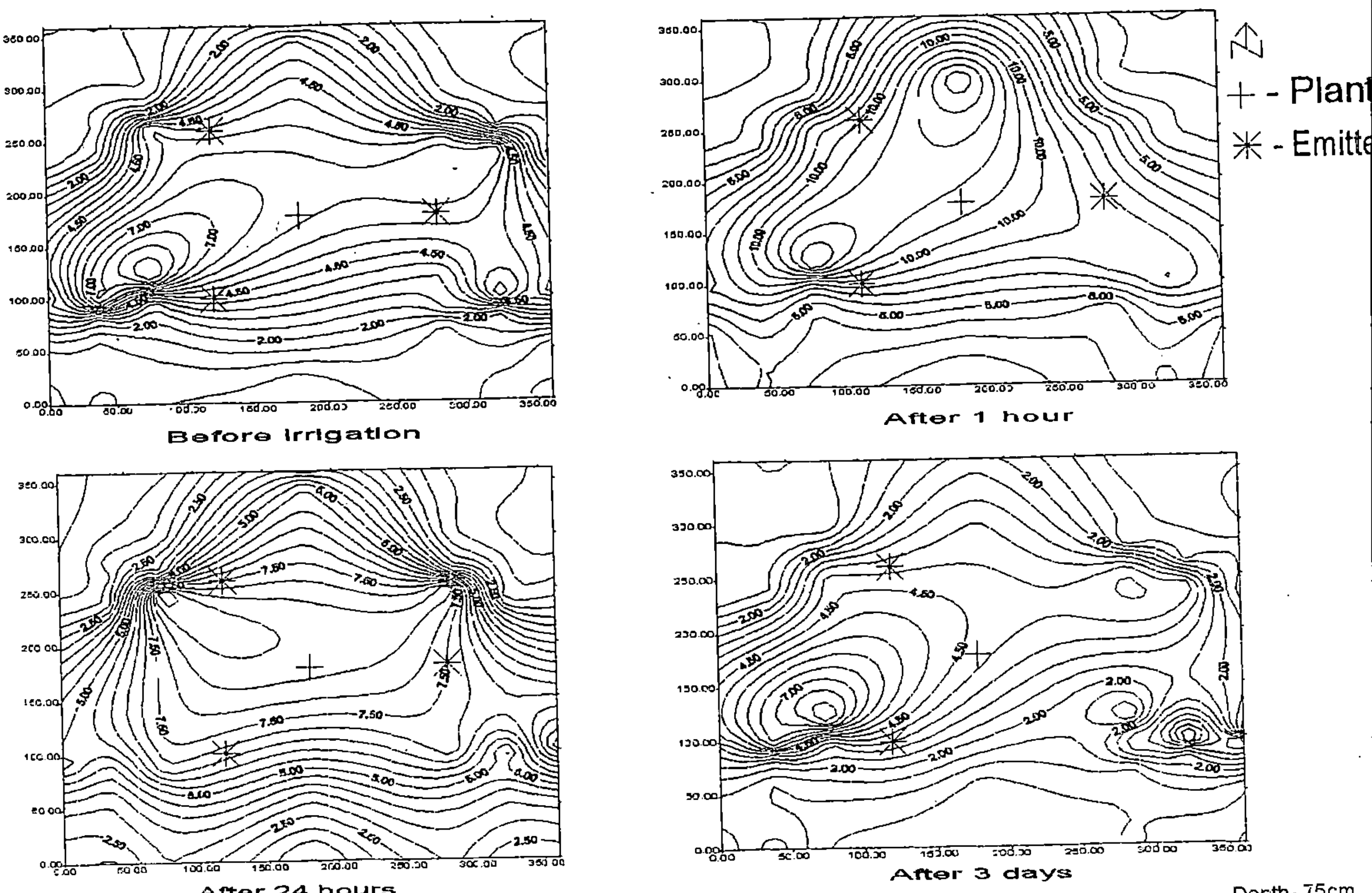
Depth - 30c
No.of emitte
Discharge- 8
Grid size- 50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (ccm)
Z-axis-Moisture content (%)

Fig. 24 Soil moisture distribution pattern - T2

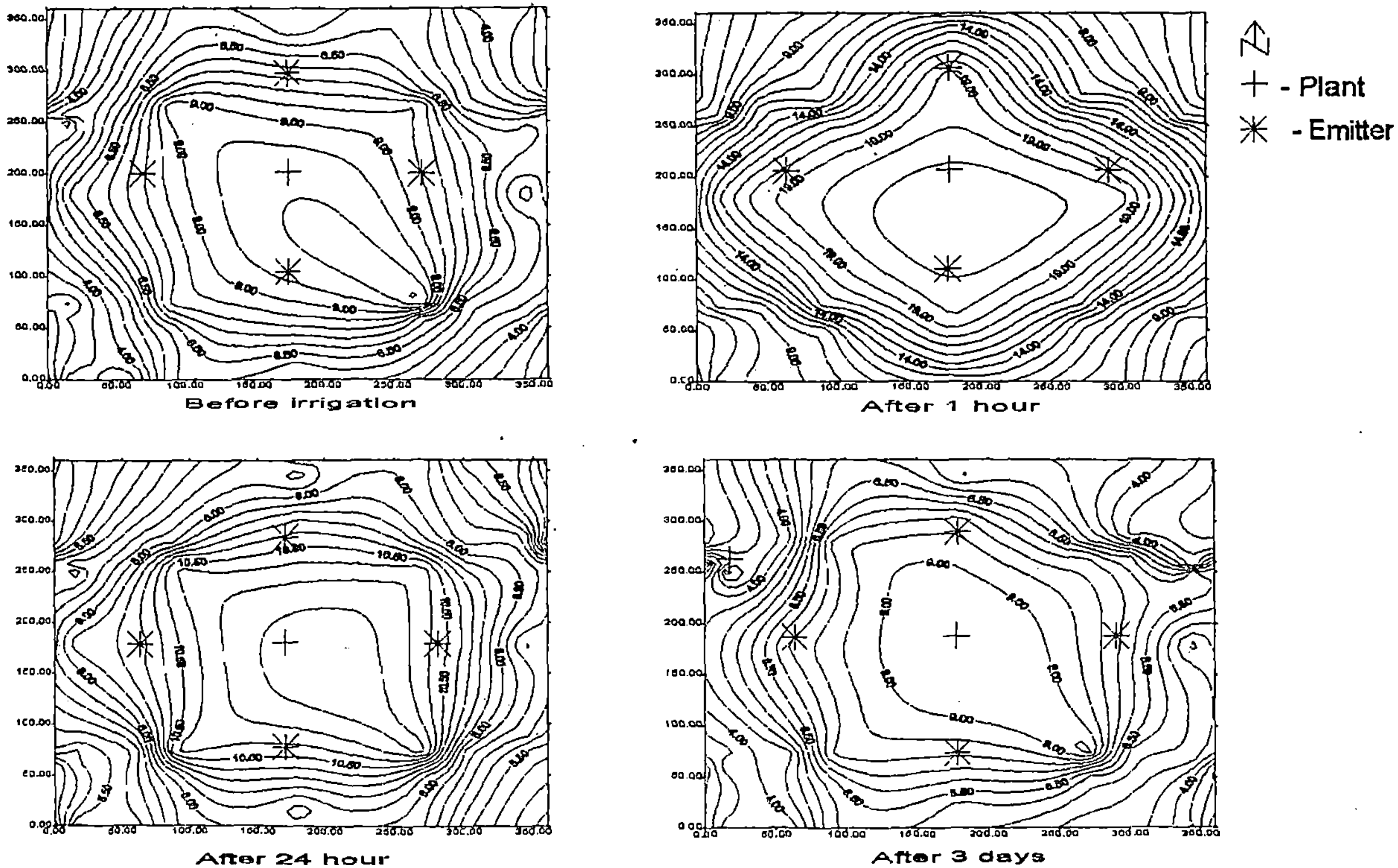
Depth- 60cm
No.of emitters- 3
Discharge- 8lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 25 Soil moisture distribution pattren - T2

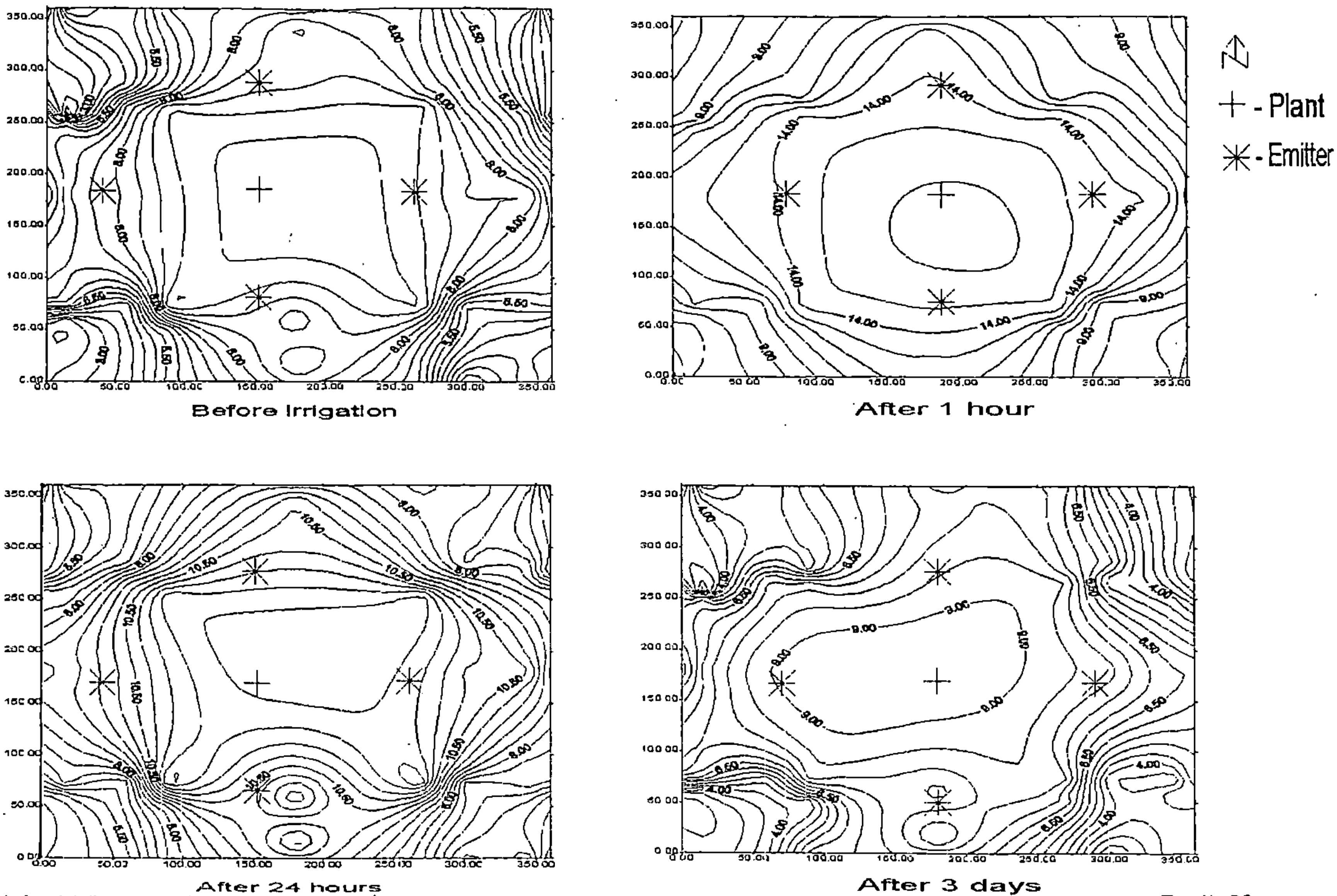
Depth- 75cm
No.of emitters
Discharge - 8l
Grid size - 50x



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig .26 Soil moisture distribution pattern- T3

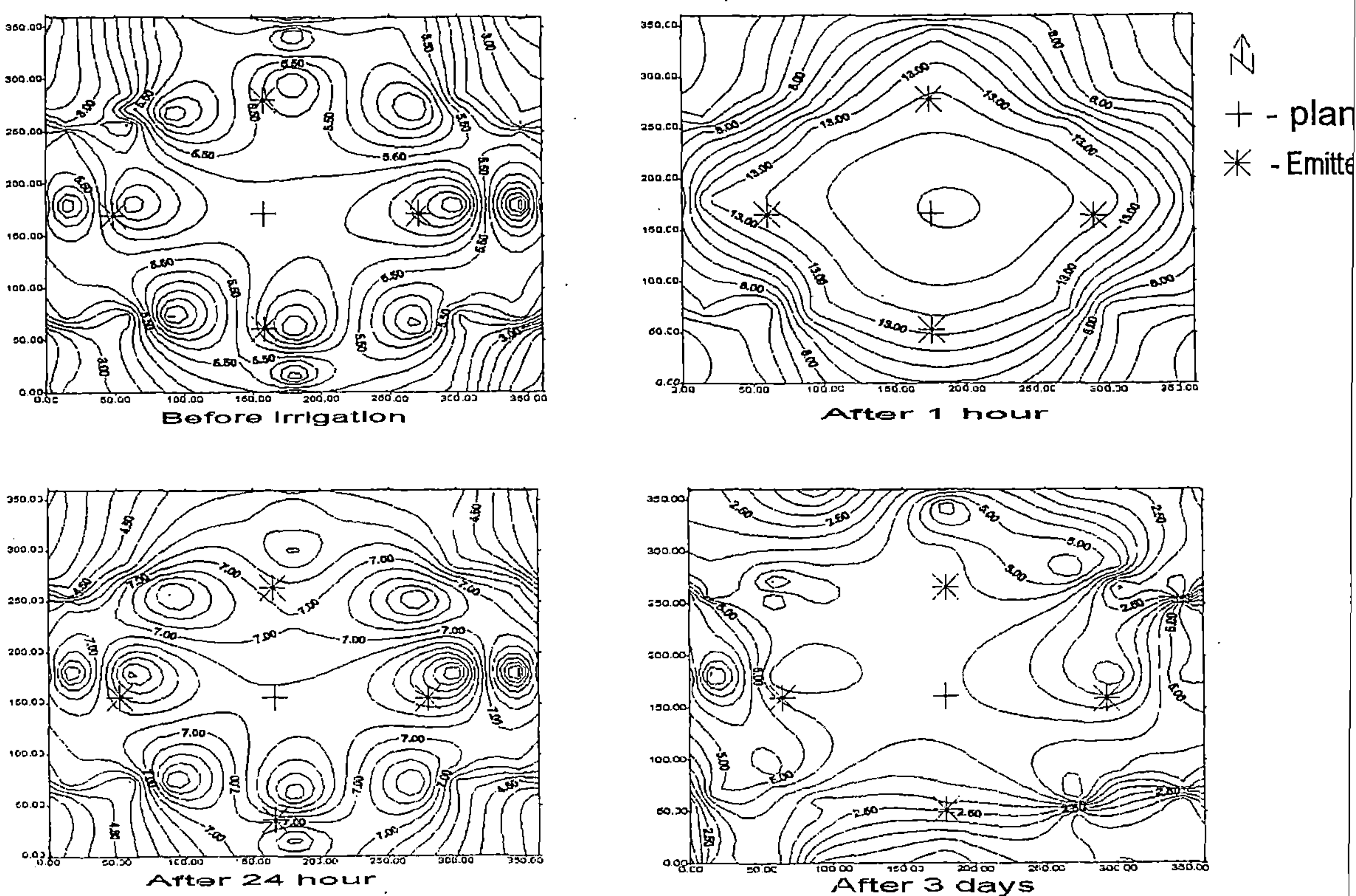
Depth- 15cm
No.of emitters- 4
Discharge-4lph
Grid size- 50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig.27 Soil moisture distribution pattern- T3

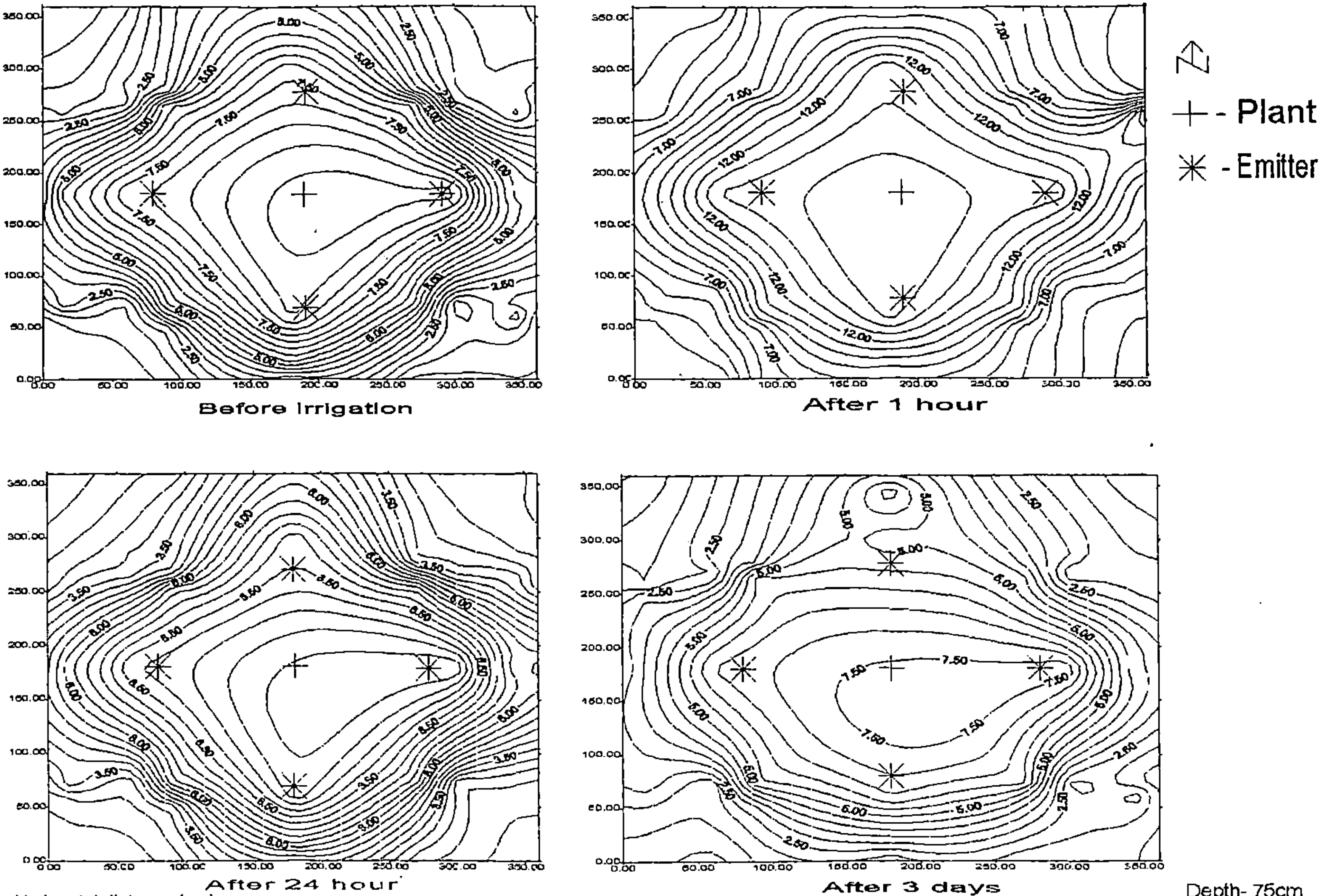
Depth-30cm
No.of emitters- 4
Discharge-4lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 28 Soil moisture distribution pattern - T3

Depth-60cm
No.of emitters- 4
Discharge - 4lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 29 Soil moisture distribution pattern - T3

Depth- 75cm
No.of emitters-4
Discharge- 4lph
Grid size -50x50

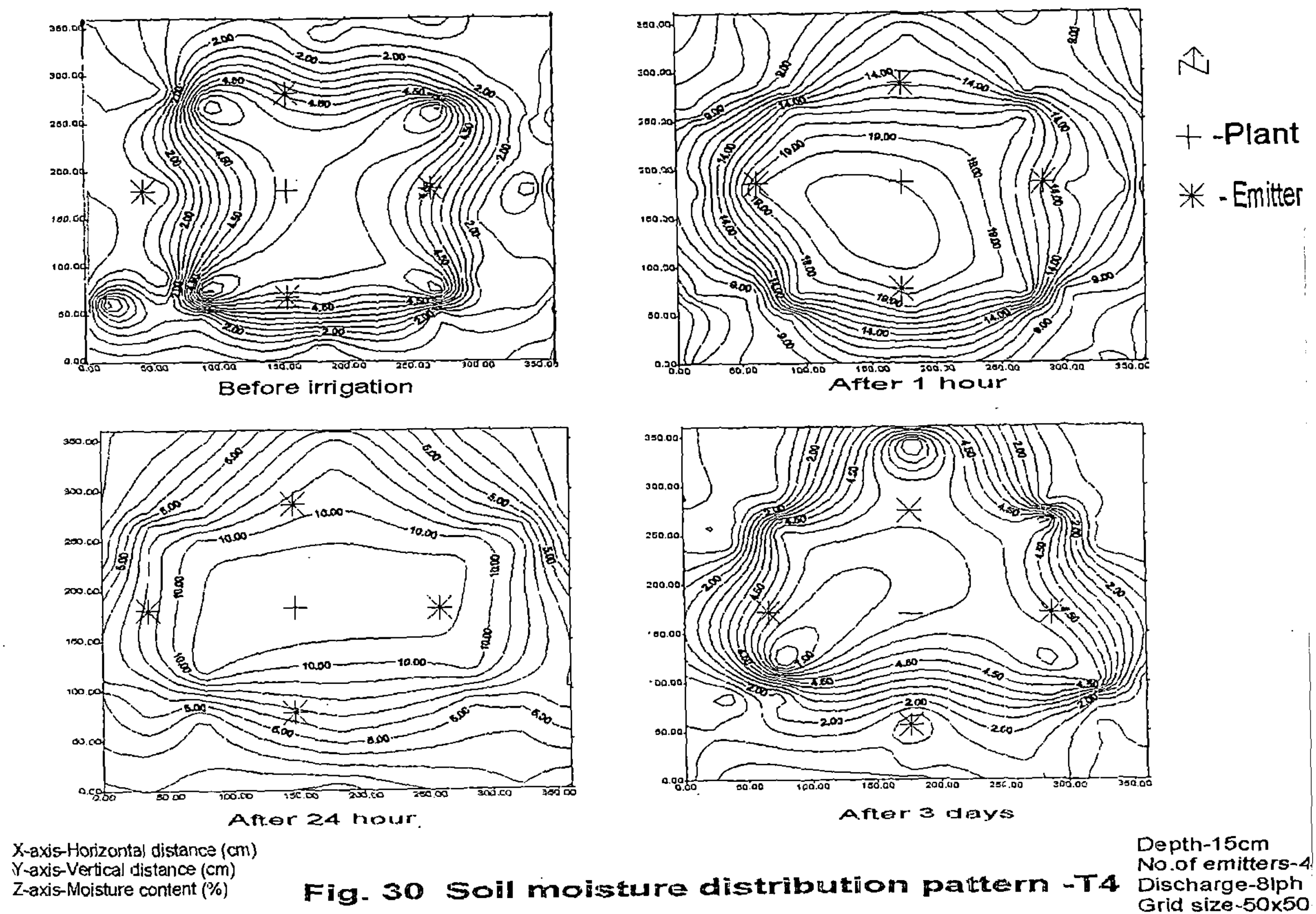
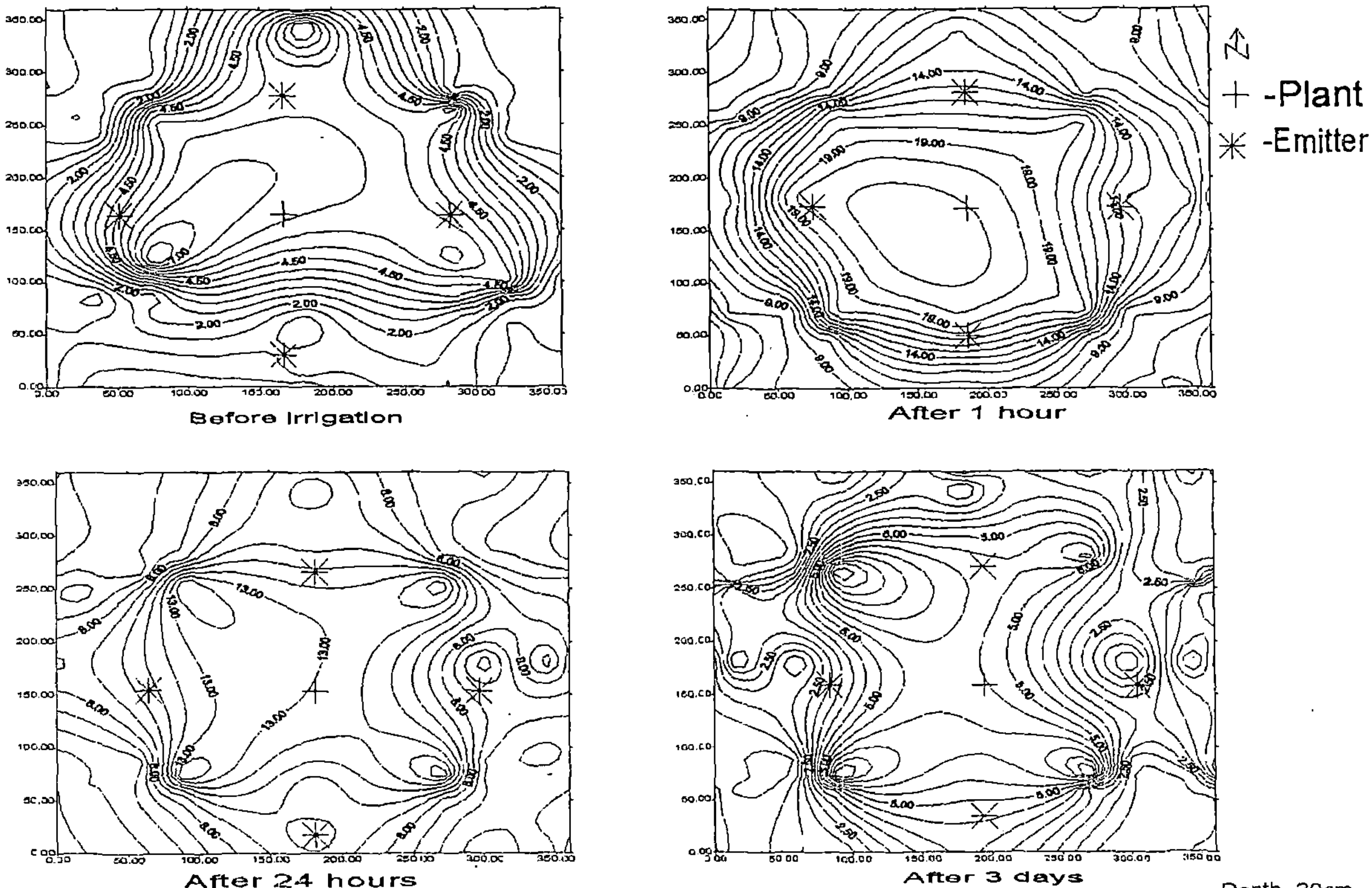


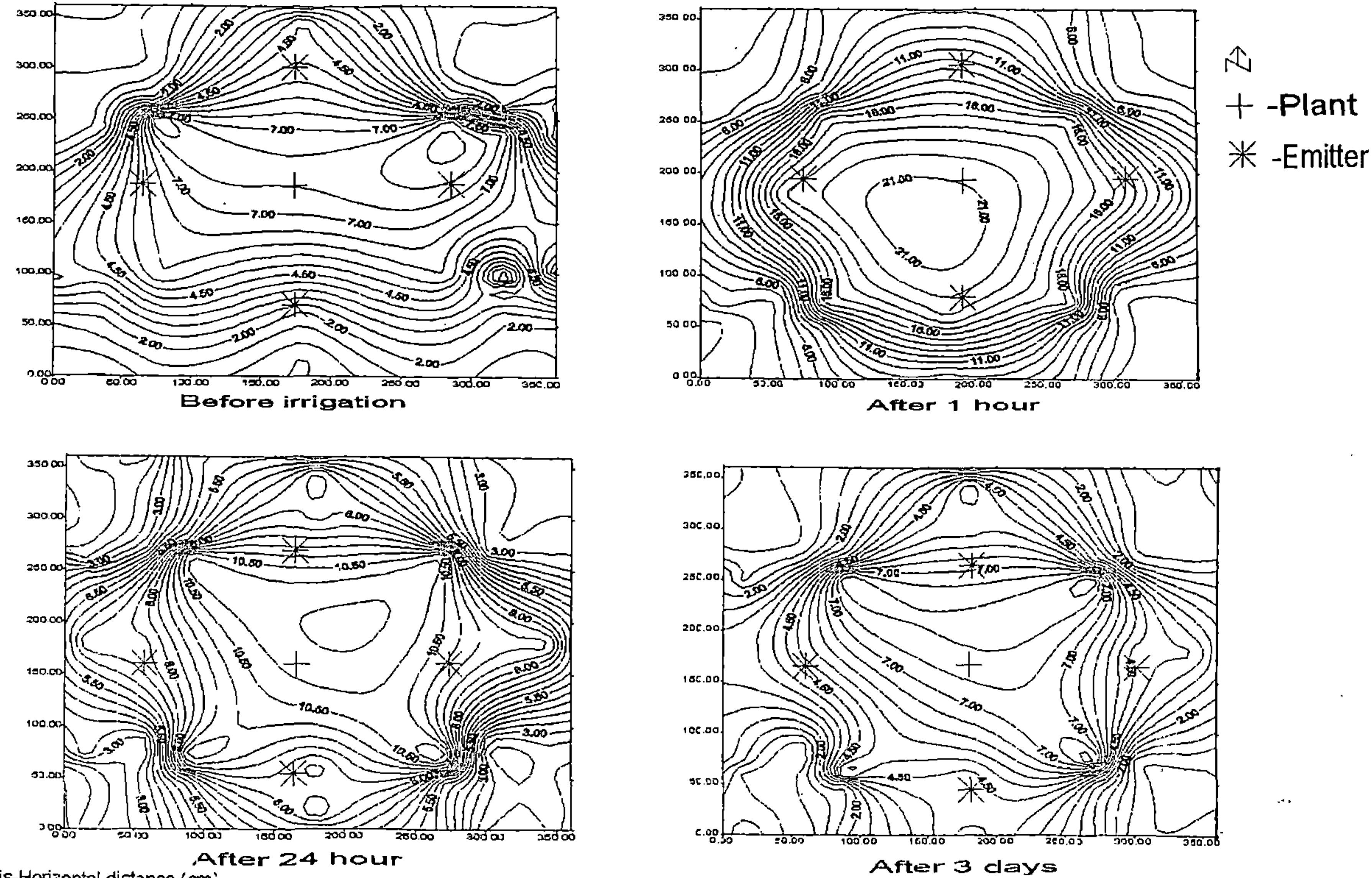
Fig. 30 Soil moisture distribution pattern -T4



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig.31 Soil moisture distribution pattern - T4

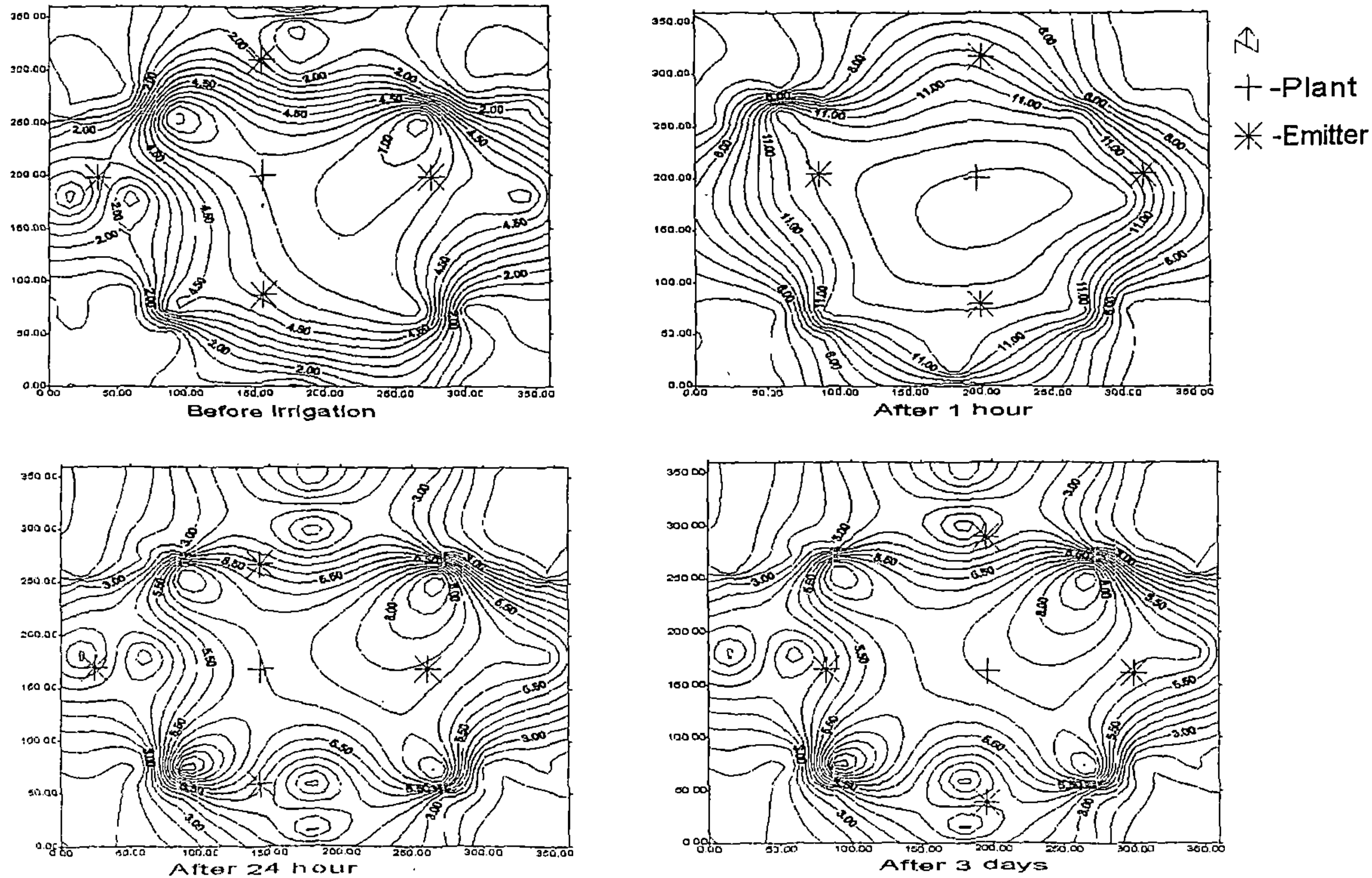
Depth -30cm
No.of emitters-4
Discharge -8lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig . 32 Soil moisture distribution pattern -T4

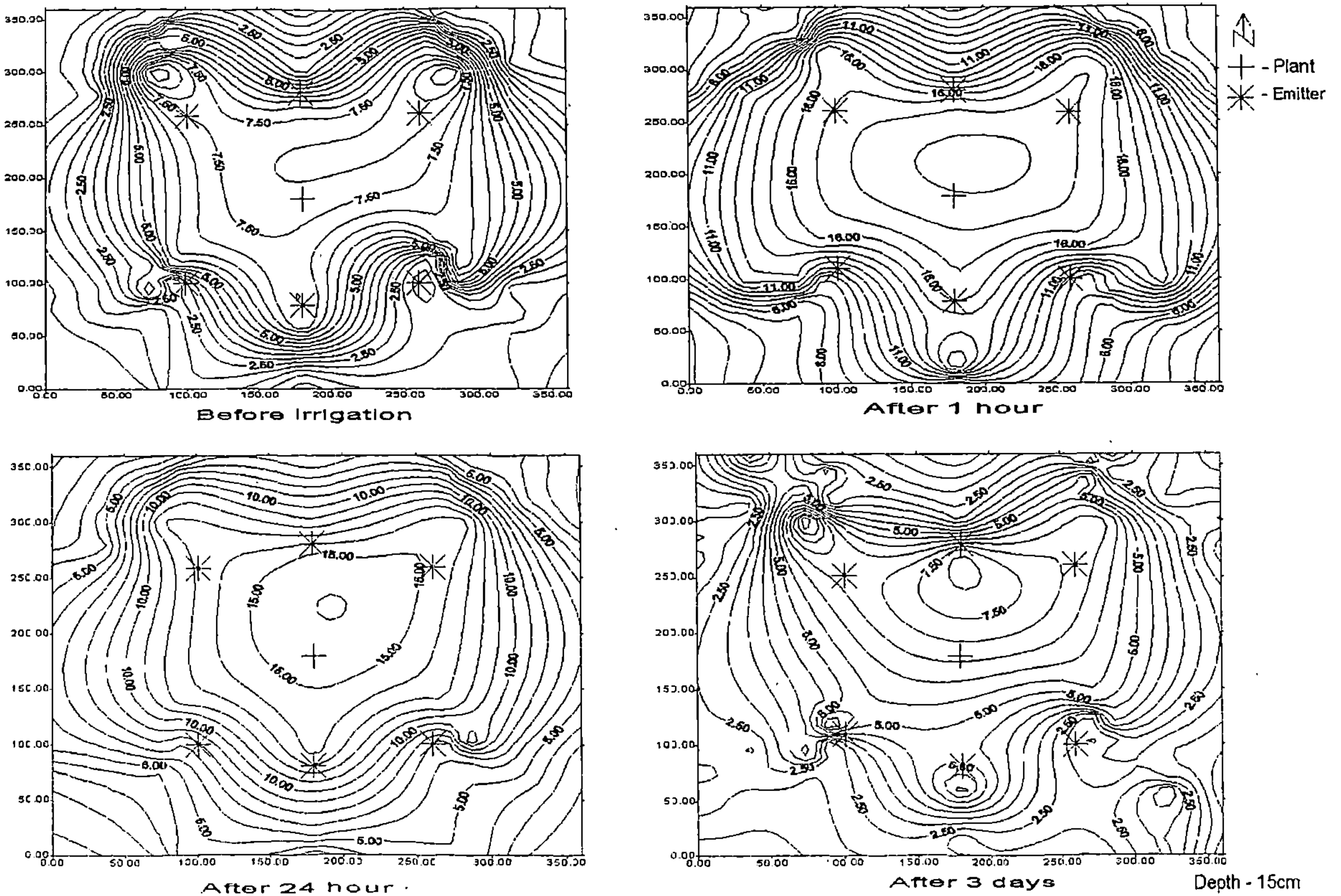
Depth-60 cm
No.of emitters-4
Discharge-8lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 33 Soil moisture distribution pattern-T4

Depth-75cm
No.of emitters
Discharge-8lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig .34 Soil moisture distribution pattern - T5

Depth - 15cm
No.of emitters - 6
Discharge - 4lph
Grid size - 50x50

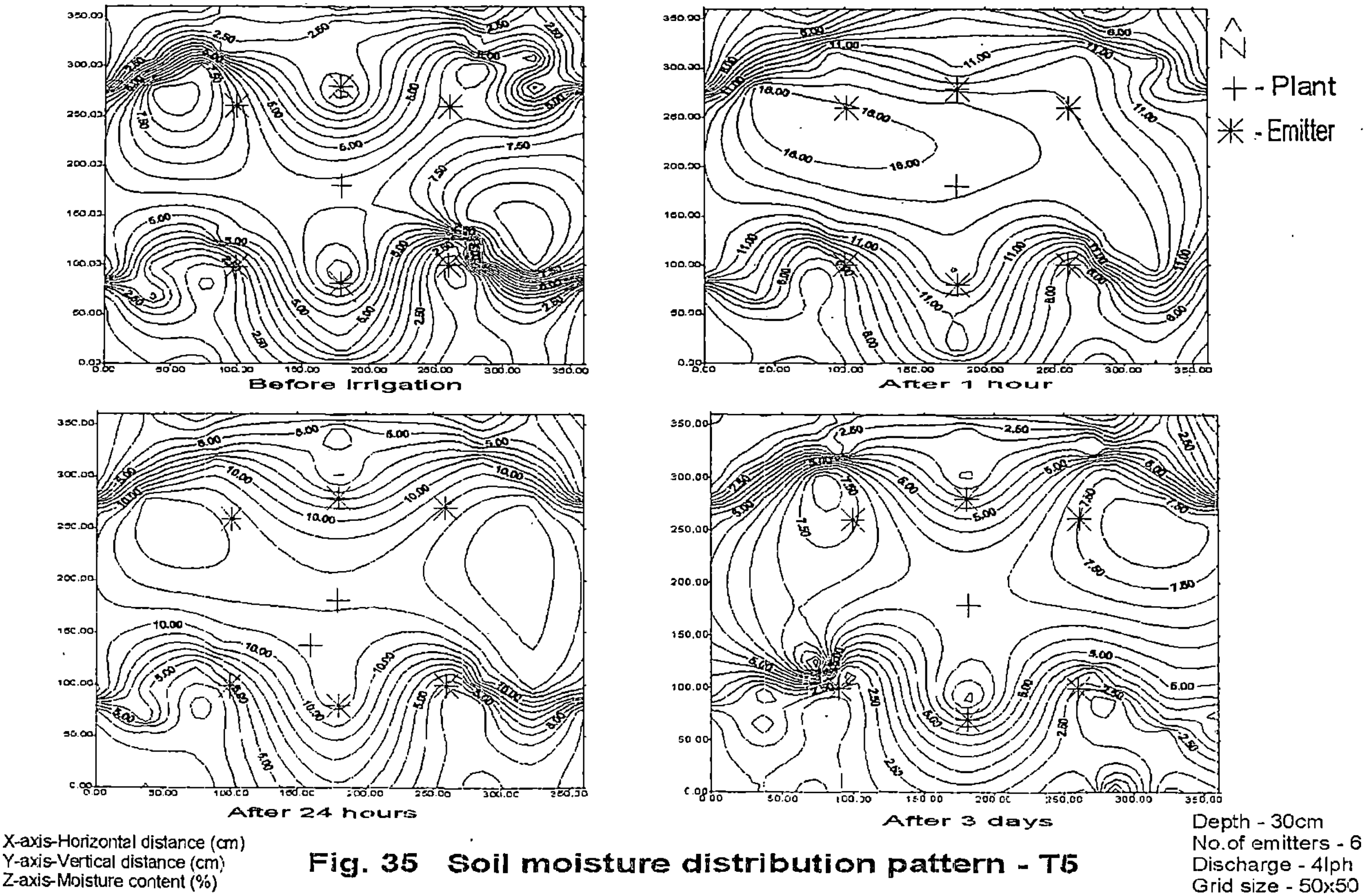
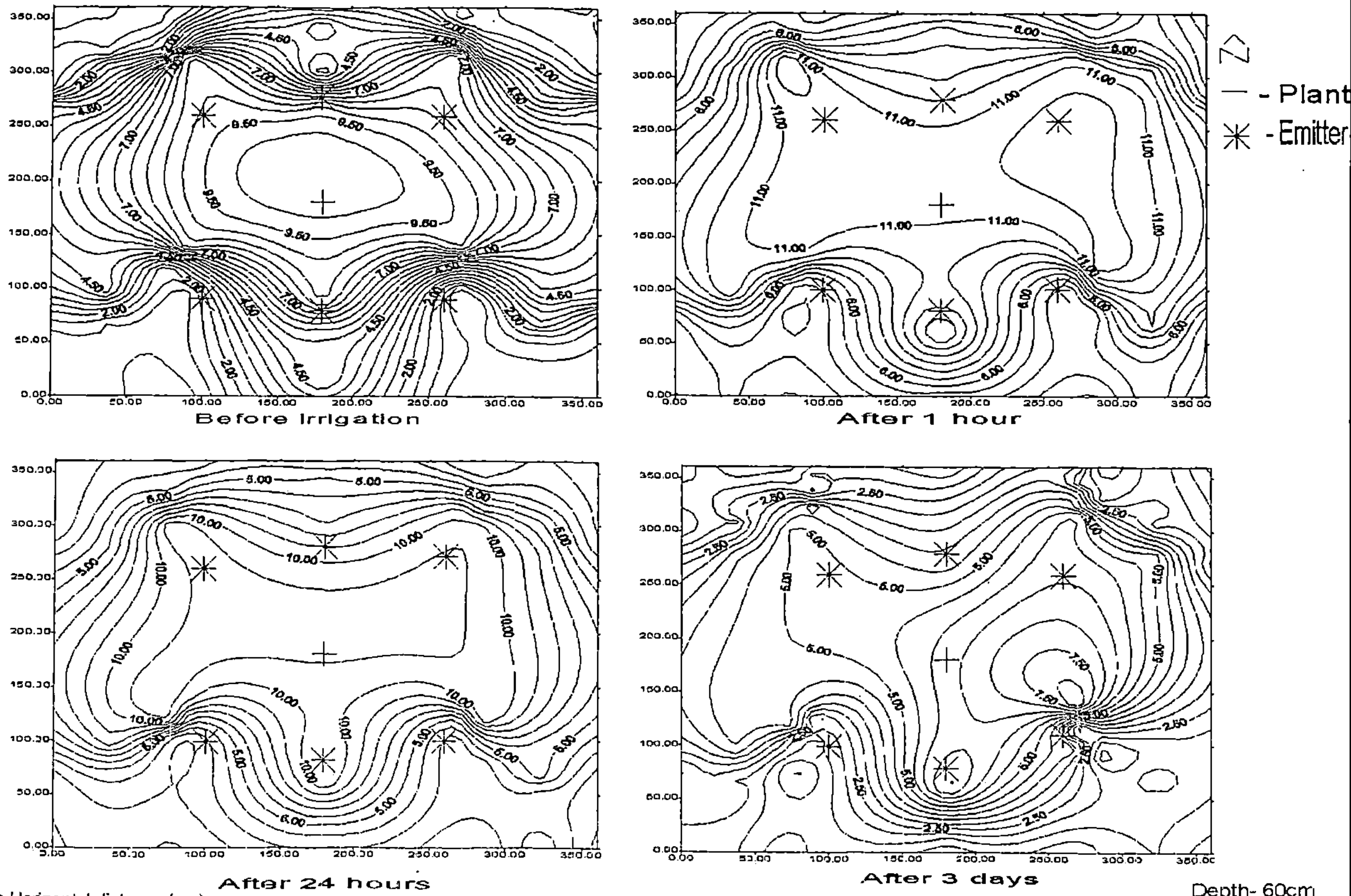


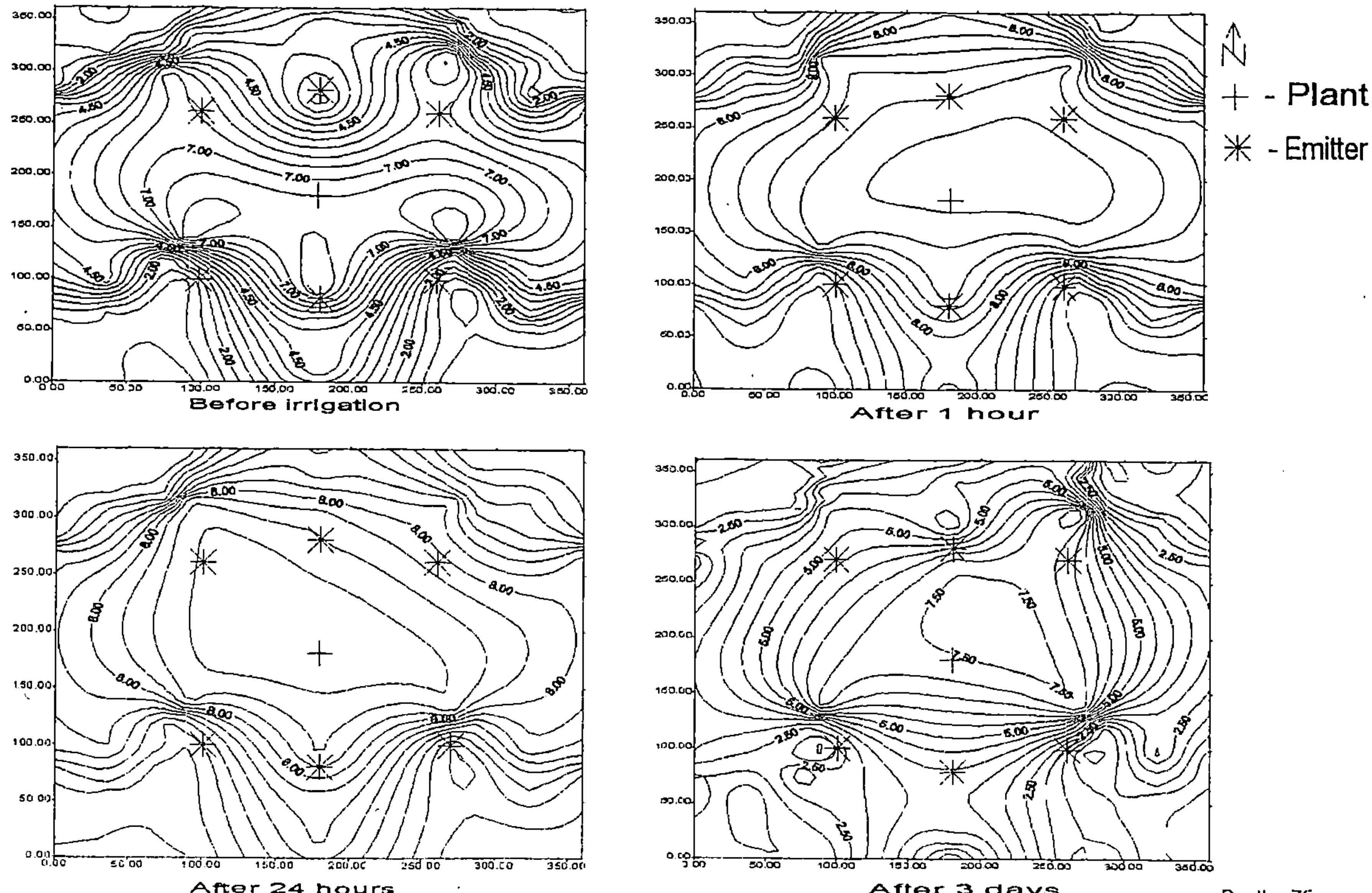
Fig. 35 Soil moisture distribution pattern - T5



X-axis-Horizontal distence (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 36 Soil moisture distribution pattern - T5

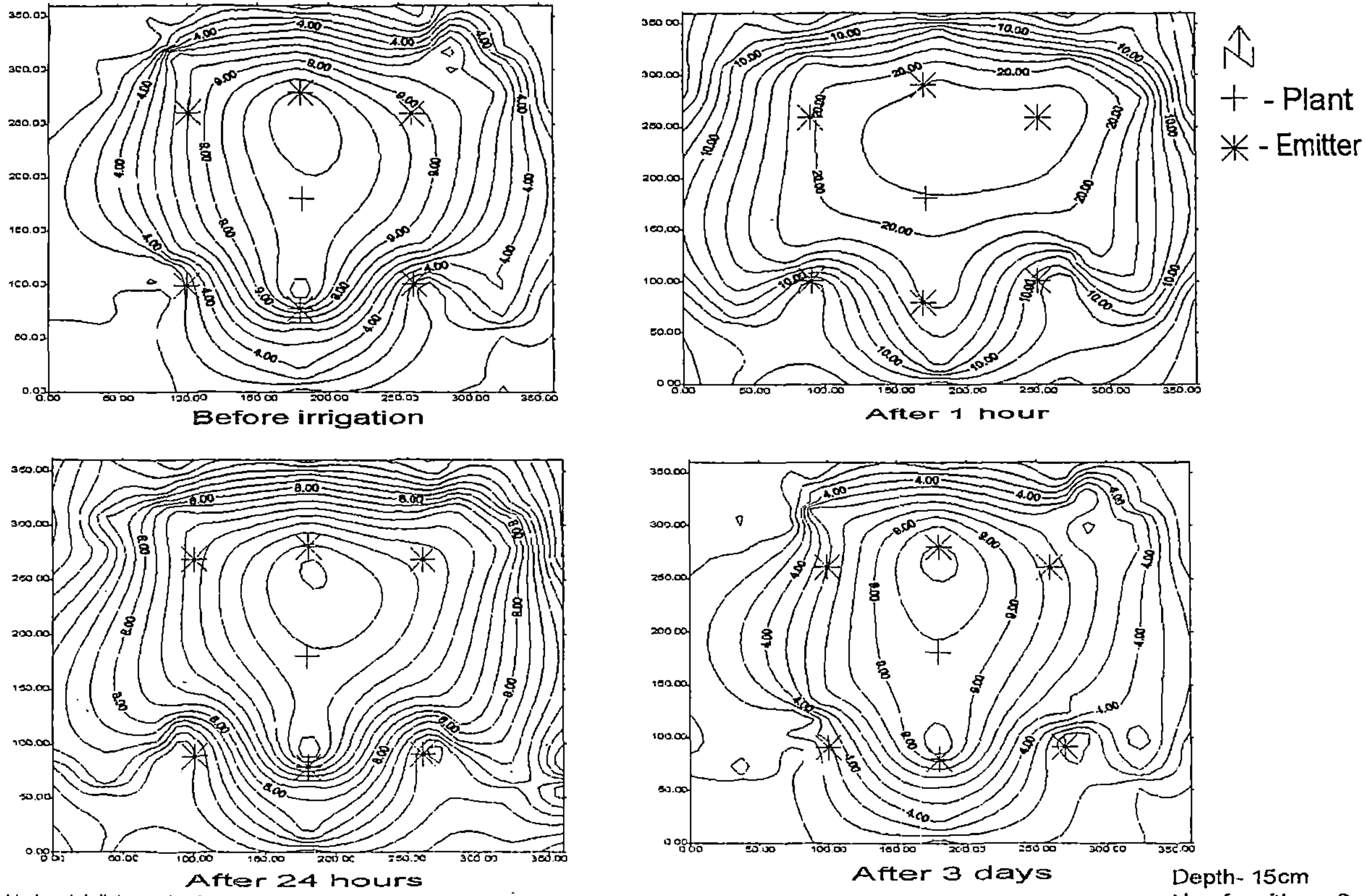
Depth- 60cm
No.of emitters -
Discharge - 4lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 37 Soil moisture distribution pattern - T5

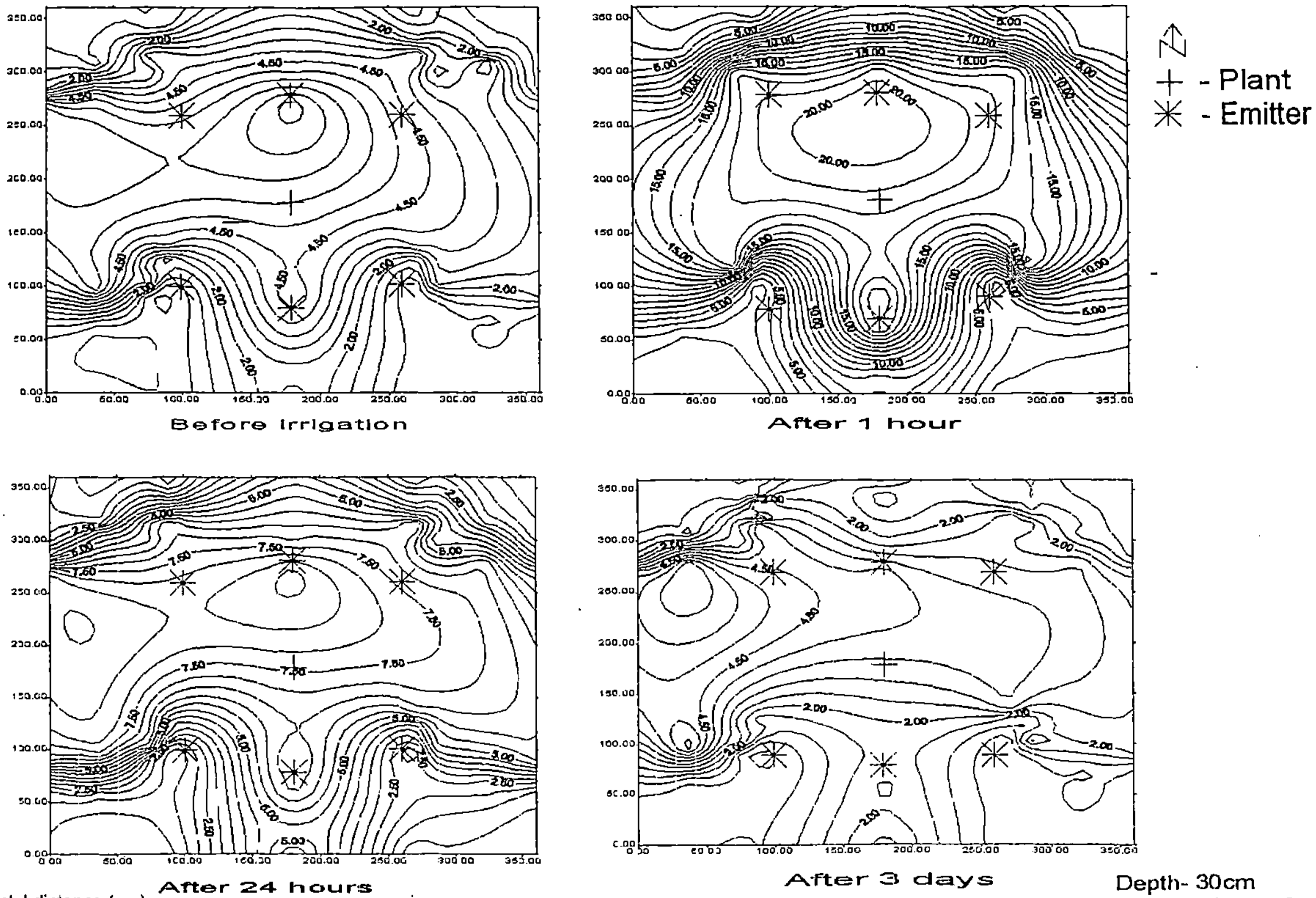
Depth - 75cm
No.of emitters- 6
Discharge - 4lph
Grid size -50x50



Depth- 15cm
No.of emitters- 6
Discharge- 8lph
Grid size -50x50

X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

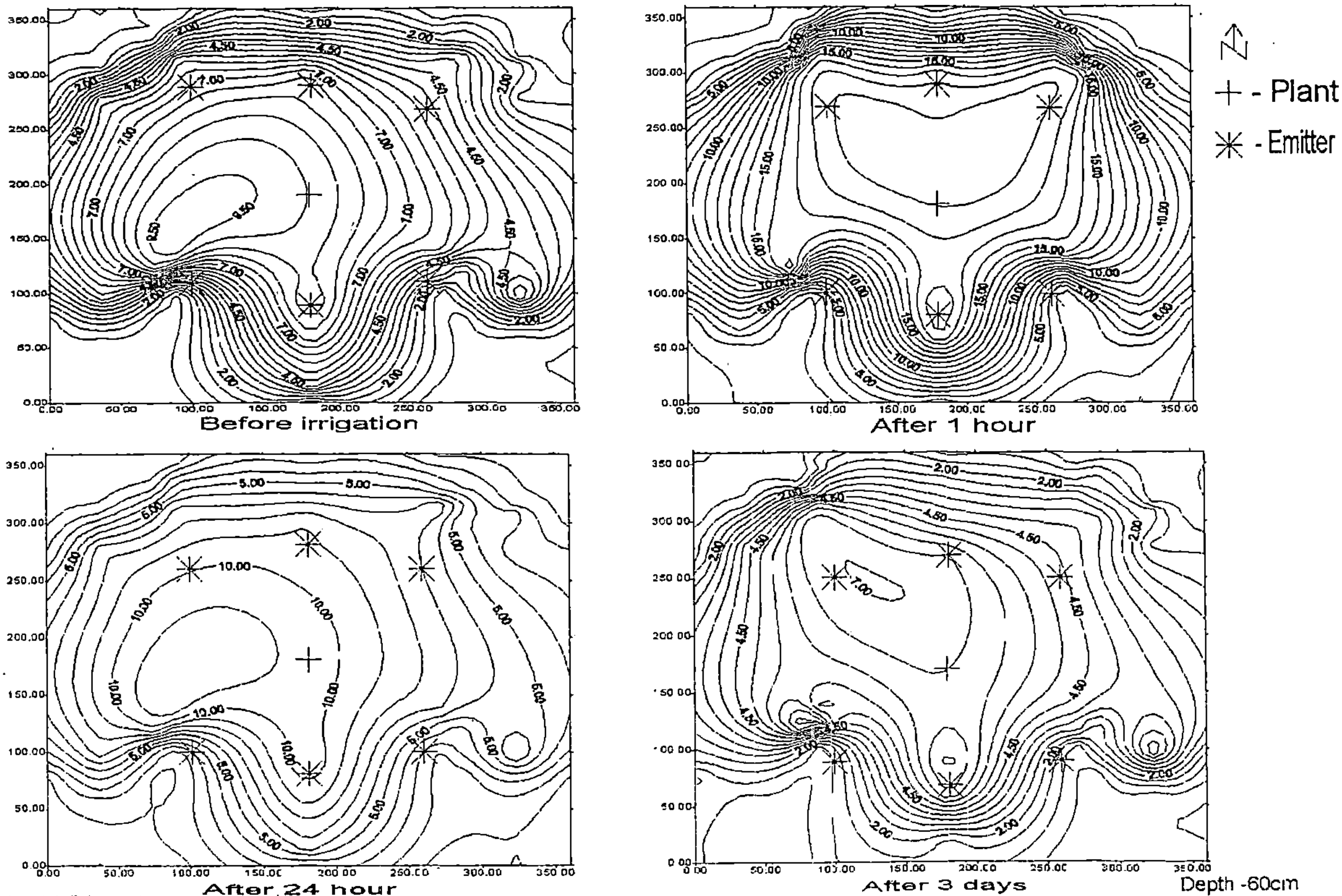
Fig .38 Soil moisture distribution pattren - T6



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-Moisture content (%)

Fig. 39 Soil moisture distribution pattern - T6

Depth- 30cm
No.of emitters- 6
Discharge- 8lph
Grid size -50x50



X-axis-Horizontal distance (cm)
Y-axis-Vertical distance (cm)
Z-axis-MOisture content (%)

Fig. 40 Soil moisture distribution pattern - T6

Depth -60cm
No.of emitters- 6
Discharge- 8lph
Grid size- 50x50

For each treatment contour maps were also prepared for various depths (15,30,60 and 75cm depths). The maps revealed that there is a distinct variation in moisture content between the points with respect to depth also. It was found that the variation in moisture content with respect to time and depth was more for 15cm depth. Since this layer is close to the surface, the atmospheric effects and evaporation causes fluctuations in moisture content. Hence more variation was noted in 15cm depth.

Among the same depths in all treatments with 4 and 8 lph emitters, more uniform distribution was observed with 4 emitters compared to 3 and 6 emitters. With 3 emitters there may not be sufficient overlapping between the wetting circle of the emitters and in case of 6 emitters overlapping of wetting circles may occur in such a way that at particular points there may be excess water. But in case of 4 emitters the overlapping of wetting circles are in a better way which causes uniform variation of moisture within the points.

Observation of the soil moisture distribution pattern also showed that the variation of moisture content among points at different depths around to be less in the case of 4 emitters both for 4 and 8 lph emitters. This may be due to the overlapping of the wetting circle in a more better way. Hence four number of emitter is found to be more suitable for coconut palm.

Among different treatments with 4 lph emitters, it was found that more uniform distribution of moisture with time and depth was found to be with 4 number of emitters. From the table 12 and 13 it can be seen that the distribution efficiency is more in the case of T_3 (i.e,with 4 number of emitters) in all depths compared to T_1 and T_5. The least efficiency was observed in the case of T_1 in all depths. This may be due to the insufficient overlapping of the wetting circle of the emitters since it consists of less number of emitters. Compared to T_1, efficiency was high in T_5 for all depths due to more number of emitters. With 3 and 6 emitters, variation of moisture content with time and depth was also observed more compared to 4 emtters.

Similarly in case of 8 lph emitter it was found that more uniform distribution of moisture with time and depth was observed with in 4 number of emitters. From the table 12 and 13 it can be seen that distribution efficiency is more in the case of T_4 (i.e, with 4 number of emitters) in all depths compared to T_2 and T_6. The least efficiency was observed in the case of T_6 for (6 number of emitters) all depths. This may be due to high discharge rate and more number of emitters which cause excess moisture content at some points. The efficiency of T_2 (3 number of emitters) is more better than T_6 due to less number of emitters. With 3 and 6 number of emitters variation of moisture content with time and depth was observed to be more compared to 4 number of emitters.

With same number of emitters (4 emitters) more uniform distribution was found in the case of 8lph emitters. In each and every layer distribution efficiency corresponding to 8 lph emitter with 4 number is found to be more. The variation of moisture content with time and depth was also found less in this case. Hence this is the most suitable combination of emitters for coconut garden in sandy loam soil.

The statistical analysis was done using the analysis of variance with the help of generalised linear model. The analysis of data corresponding to selected test series (II) was done. The results of the analysis are presented in Appendix V. The results show that there is a significant difference of moisture distribution for different discharge rates, number of emitters, depth and horizontal distance at 1 hour and 24 hours after irrigation. The mean distribution efficiency at different depths (horizontal planes) for different treatments shows that distribution efficiency observed for T_4 significantly differs from other treatments. From the above analysis maximum uniform distribution was found in T_4. So the T_4 is the optimal discharge and emitter combination for coconut garden in sandy loam soil.

Summary and Conclusion

SUMMARY AND CONCLUSION

The present study has been carried out with the objective of determining the "Optimal number and discharge rate of emitters for coconut palm in sandy loam soil". The main design requirement of a drip system involves the optimum spacing of emitters, correct discharge rates and duration of irrigation based on the soil moisture distribution. Two different discharge rates (4 and 8lph) and three combinations of emitter numbers (3,4 and 6) were taken for the study. The soil properties viz: texture, infiltration rate, bulk density, field capacity, hydraulic conductivity and permanent wilting point were analyzed. The drip system was laid out in the field.. The ponded zone and the horizontal and vertical advances with respect to elapsed time were noted for both discharges. The equations for vertical and horizontal advances with respect to elapsed time were developed. Soil moisture profiles were plotted for both the discharge rates at different time intervals. The soil moisture content at various points were determined by gravimetric method. The distribution efficiency for all the treatments at different depths were calculated. The soil moisture contour maps for each treatment were prepared for different depths by noting the data of soil moisture before irrigation, 1 hour, 24 hours and 3 days after irrigation.

From the results of the study it can be concluded that:

1) In the case of both 4 and 8 lph emitters there was a high variation of ponded zone radius at 20 to 30 minutes, compared to other time intervals.
2) The variation of ponded zone radius with respect to time became zero at 30 minutes (i.e. ponded zone radius attains a constant value) for 4 lph emitter, but in case of 8 lph emitter the ponded zone radius with respect to time attained a constant value only after 50 minutes.
3) The radius of ponded zone with respect to time was observed more for 8 lph emitters compared to 4 lph emitters.

4) For 4 lph emitter, maximum horizontal wetting radius was found at the surface, where as in 8lph emitter the maximum horizontal wetting radius was found at the surface up to 50minute only.

5) In case of 4 lph emitter both horizontal and vertical wetting radius attained a constant value (maximum value) at 120 minutes, where as in 8lph emitter horizontal and vertical wetting radius attained a constant value only at 180 minutes.

6) In case of both 4 and 8 lph emitters, for a particular time interval, vertical wetting radius was more compared to horizontal wetting radius. Hence the movement of water in vertical direction was faster than that in horizontal direction.

7) The horizontal and vertical wetting radius was found more for 8 lph emitter than 4 lph at all time.

8) The soil moisture profile at various time intervals for both the discharge rates (4 lph and 8 lph) revealed that the wetting front from a single emitter produces a bulb like wetting pattern in sandy loam soil. It was also found that the size of the wetting bulb at a particular time increases with increase in discharge rate.

9) The vertical advance against elapsed time showed an exponential relationship.

10) The horizontal advance against elapsed time showed a power function.

11) In case of 4 lph emitters, distribution efficiency was found more in T_3 at all depths. Variation of moisture content with respect to time and depth was observed less in this case. Compared to T_1, distribution efficiency was found more in T_5 at all depths.

12) Among different treatments with 4 lph emitters more uniform distribution of moisture with time and depth was found in the case of 4 number of emitters

13) In case of 8 lph emitters, distribution efficiency was found more in case of T_4 in all depths. Variation of moisture content with respect to time and depth was observed less in this case compared to T_2 and T_6.

The distribution efficiency was found more in T $_2$ compared to T_6 at all depths and time.

14) With same number of emitters (4 emitters) distribution efficiency was observed more for T_4 (8lph emitters) compared to T_3 (4lph emitters) at all depths and time.

15) The soil moisture contour maps also revealed that T_4 (8 lph,4 number emitters) gives more uniform distribution in all depths and time of observation.

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Appendix I

GRAIN SIZE DISTRIBUTION OF THE SOIL (COARSE FRACTION)

Sl No.	IS sieve	Particle Size D (mm)	% retained	Mass retained (g)	Culmulative % retained	Culmulative % finer (N)
1	4.75	4.75	1.67	16.7	1.67	98.33
2	2	2	1.22	12.2	2.89	97.11
3	1	1	4.5	45	7.39	92.61
4	600	0.6	11	110.07	18.39	81.61
5	425	0.425	15.5	155.58	33.89	66.11
6	300	0.3	13.8	138.19	47.69	52.31
7	212	0.212	14.6	146.53	62.29	37.71
8	150	0.15	6.6	66.89	69.29	30.71
9	75	0.075	1.9	19.29	71.19	28.81

Appendix II
GRAIN SIZE DISTRIBUTION OF THE SOIL (FINE FRACTION)

Mass of dry soil sample (M) = 1056 g
Mass of fraction passing 2mm sieve (M') = 673 g
Mass of dry soil sample taken from minuts 2mm sieve (M_d) = 100 g
Specific gravity of soil particle of minus 75 micron G = 2.65

Date	Time	Elapsed time, t(min)	Temperat-ure (°C)	Hydrometer reading R_h	Effective depth, the (cm)	Factor M	Particle size D(mm)	% finer (N) based on M_d	% finer (N) based whole N = N'xM'/M
2/1/99	11.15	1/2	32	28.65	7.9	1193	0.061	44.16	28.71
		1	32	25.5	8.7	1193	0.035	40.95	26.11
		2	32	24.15	9	1193	0.025	38.78	24.71
		4	32	23.5	9.2	1193	0.018	37.74	24.05
		8	32	22.0	9.6	1193	0.013	33.72	21.49
		15	33	21.4	9.8	11.80	0.0095	34.36	21.9
	11.45	30	,,	20.0	10.4	11.80	0.007	32.12	20.47
	12.58	63	,,	19.0	10.8	11.80	0.0049	30.15	19.44
	2.55	113	36	18.25	11.1	1144	0.004	29.31	18.67
	6.55	240	33	17.0	11.6	1180	0.0025	27.3	17.4
	3.00	513	33	15.2	12.0	1180	0.0018	24.41	15.55
	1.45	1408	36	12.6	13.1	1144	0.0010	20.23	12.89

Specific gravity of soil
Mass of bottle, M_1 = 14.91
Mass of bottle+ soil, M_2 = 34.91
Mass of bottle + wate M_4 = 68.40
Specific gravity G = M_2-M_1/ (M_2-M_1) - (M_3-M_2)
= 34.91-14.91/(34.91-14.91)- (80.84-34.15)
= 2.65

Calibration of Hydrometer

Volume of hydrometer (V_h) = 88 cm^3
Height of bulb (h) = 15.5cm
Sectional area of jar A = 28.27 cm^2
Constant 1/2 (V_h-V_h/A) = 1/2 (15.5 - 88/28.27) = 6.19 cm

Hydrometer Reading R_h	H (cm)	Effective depth H_e (cm)
30	1.5	7.693
25	2.7	8.893
20	4.2	10.393
15	5.9	12.093
10	7.3	13.493
5	9.5	15.693
0	11	17.193
-5	13	19.193

Appendix III

DERIVATION OF INFILTRATION EQUATION

From the plot of y against t (fig.10)

For $t_1 = 5$ minutes $y_1 = 1.7$cm

$t_2 = 130$minutes $y_2 = 19.12$

Adopting the procedure suggested by Davis (1943), the rectifying value is found from the relation.

$$t_3 = \sqrt{t_1 t_2} = \sqrt{5x130} = 25.49 \text{ minutes}$$

The corresponding value of y_3 as determined from fig is 5.63 cm. The value of constant b is obtained as follows.

$$b = y_1y_2 - y_3^2/y_1 + y_2 - 2y_3 = 1.7x19.12-(5.6)^2/1.7+19.12-2x5.6 = 0.11$$

The value 0.11 of b is subtracted from each value of y. The logarithms of (y-0.11) and t are taken. The variable are related by the expression

$$y-0.11 = at^{\alpha}$$

The logarithmic form of which is $\log (Y-.11) = \log a + \alpha \log \mathbf{t}$

Substituting the data on average infiltration y and elapsed time t presented in table in the equation $\log (y-.11) = \log a + \alpha \log t$ yields the following equations.

0.2013	=	$\log a + 0.6990\ \alpha$
0.4871	=	$\log a + 1.000\ \alpha$
0.6031	=	$\log a + 1.1761\ \alpha$
0.7427	=	$\log a + 1.3979\ \alpha$
0.9153	=	$\log a + 1.6532\ \alpha$
1.0064	=	$\log a + 1.7782\ \alpha$
1.0792	=	$\log a + 1.8751\ \alpha$
1.1565	=	$\log a + 1.9542\ \alpha$
1.2219	=	$\log a + 2.0414\ \alpha$
1.2789	=	$\log a + 2.1139\ \alpha$

Adding the first five and last five equations

2.9495	=	5 loga + 5.9262 α
5.7429	=	5 loga + 9.7268 α
-2.7934	=	-3.866 α
α	=	0.72
log a	=	-0.22531
a	=	0.56

The values of t are substituted in the equation as follows the logarithmic form

Log (y-b) = log a + α log t

T= 5 minutes	log (y1-0.11)	=	-0.2531+0.72x0.6990
		=	1.819+0.11=1.88cm
T= 10 minutes	log (y2-0.11)	=	-0.2531+0.72x1.0
		=	2.93+0.11=3.04cm
T= 15 minutes	log (y3-0.11)	=	-0.2531+0.72x1.1761
		=	3.92+0.11=4.05cm
T= 25 minutes	log (y4-0.11)	=	-0.2531+0.72x1.3974
		=	5.66+0.11=5.77cm
T= 45 minutes	log (y5-0.11)	=	-0.2531+0.72x1.6532
		=	8.65+0.11=8.76cm
T= 60 minutes	log (y6-0.11)	=	-0.2531+0.72x1.7782
		=	10.65+0.11=10.76cm
T= 75 minutes	log (y7-0.11)	=	-0.2531+0.72x1.8751
		=	12.5+0.11=12.61cm
T= 90 minutes	log (y8-0.11)	=	-0.2531+0.72x1.9542
		=	14.25+0.11=14.36cm
T= 110 minutes	log (y9-0.11)	=	-0.2531+0.72x2.0414
		=	16.47+0.11=16.58cm
T= 130 minutes	log (y10-0.11)	=	-0.2531+0.72x2.1139
		=	18.57+0.11=18.68cm

Appendix IV

The daily evaporation rate observed during the experiment study.

Date	Pan Evaporation (mm)
10/3/99	9.9
11 /3/99	10
12/3	9.8
13/3	9.8
14/3	10
15/3	10.1
16/3	10.1
17/3	10.0
18/3	10.1
19/3	10.1
20/3	10.2
21/3	10.2
22/3	10.1
23/3	10.2
24/3	10.2
25/3	10.2
26/3	10.3
27/3	10.3
28/3	10.3
29/3	10.4
30/3	10.3
31/3	10.3
1/4	10.4
2/4	10.4
3/4	10.3
4/4	10.5
5/4	10.4

6/4	10.5
7/4	10.6
8/4	10.5
9/4	10.6
10/4	10.6
11/4	10.5
12/4	10.5
13/4	10.5
14/4	10.6
15/4	10.6
16/4	10.7
17/4	10.7
18/4	10.7
19/4	10.8
20/4	10.6
21/4	10.8
22/4	10.8
23/4	10.8
24/4	10.7
25/4	10.8
26/4	10.7
27/4	10.7
28/4	10.7
29/4	10.8
30/4	10.7
1/5	10.8
2/5	10.7

Results of statistical analysis for different treatments

DIS1 NOEM2 DEPTH3 HORI4 MC1HR5 MC24HR6

72 case(s) deleted due to missing data.

Dep Var: MC1HR5 N: 216 Multiple R: 0.788 Squared multiple R: 0.621

Adjusted squared multiple R: 0.614 Standard error of estimate: 3.268

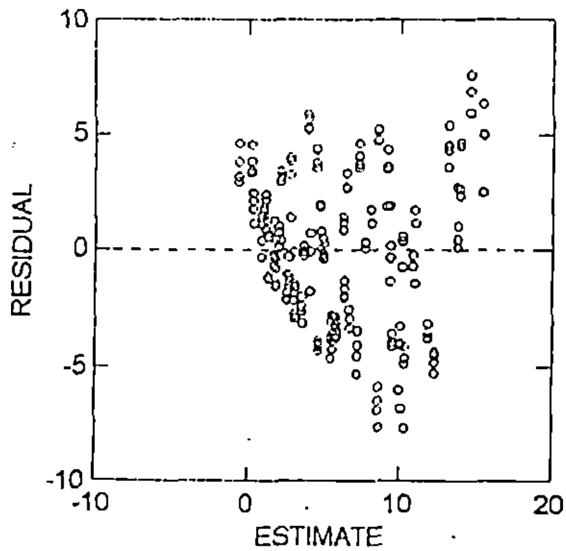
Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tail)
CONSTANT	21.660	1.256	0.000	.	17.241	0.000
DIS1	1.486	0.445	0.142	1.000	3.340	0.001
NOEM2	-0.840	0.272	-0.131	1.000	-3.083	0.002
DEPTH3	-3.676	0.244	-0.696	0.844	-15.090	0.000
HORI4	-4.629	0.308	-0.693	0.844	-15.025	0.000

Analysis of Variance

	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	3691.496	4	922.874	86.410	0.000
Residual	2253.523	211	10.680		

Durbin-Watson D Statistic 0.613
First Order Autocorrelation 0.689

Plot of Residuals against Predicted Values



```
Durbin-Watson D Statistic       0.707
First Order Autocorrelation     0.641
COL/
ROW DIS1
  1  1
  2  2
Using least squares means.
Post Hoc test of MC1HR5
```

```
Using model MSE of 0.824 with 162 df.
Matrix of pairwise mean differences:

                      1          2
           1        0.000
           2        0.742      0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

                      1          2
           1        1.000
           2        0.009      1.000
```

```
COL/
ROW NOEM2
  1  1
  2  2
  3  3
Using least squares means.
Post Hoc test of MC1HR5
```

```
Using model MSE of 0.824 with 162 df.
Matrix of pairwise mean differences:

                      1          2          3
           1        0.000
           2        1.371      0.000
           3       -1.077     -2.448      0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

                      1          2          3
           1        1.000
           2        0.000      1.000
           3        0.025      0.000      1.000
```

```
COL/
ROW DEPTH3
  1  1
  2  2
  3  3
  4  4
Using least squares means.
Post Hoc test of MC1HR5
```

Using model MSE of 0.824 with 162 df.
Matrix of pairwise mean differences:

	1	2	3	4
1	0.000			
2	-6.112	0.000		
3	-1.732	4.380	0.000	
4	7.843	13.955	9.575	0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

	1	2	3	4
1	1.000			
2	0.000	1.000		
3	0.000	0.000	1.000	
4	0.000	0.000	0.000	1.000

```
COL/
ROW HORI4
  1  1
  2  2
  3  3
Using least squares means.
Post Hoc test of MC1HR5
```

Using model MSE of 0.824 with 162 df.
Matrix of pairwise mean differences:

	1	2	3
1	0.000		
2	1.291	0.000	
3	3.580	2.288	0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

	1	2	3
1	1.000		
2	0.000	1.000	
3	0.000	0.000	1.000

Effects coding used for categorical variables in model.

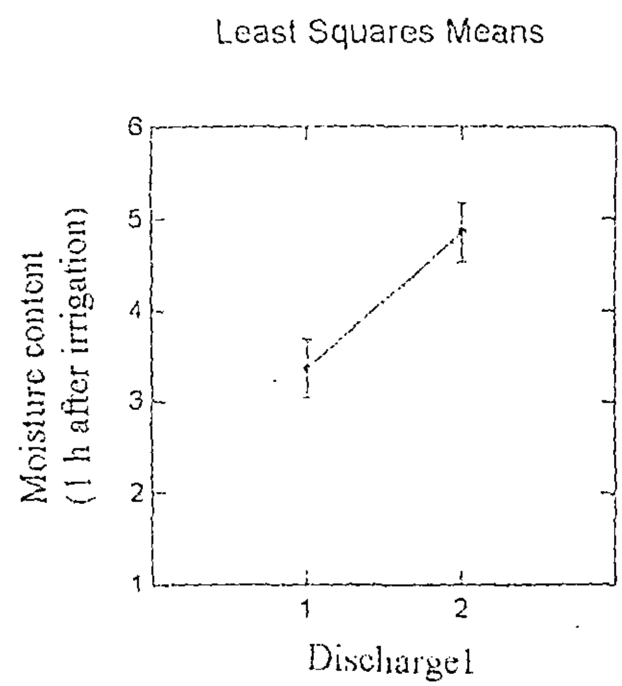
Categorical values encountered during processing are:
DIS1 (2 levels)
1, 2
NOEM2 (3 levels)
1, 2, 3
DEPTH3 (4 levels)
1, 2, 3, 4
HORI4 (3 levels)
1, 2, 3
72 case(s) deleted due to missing data.

Dep Var: MC1HR5 N: 216 Multiple R: 0.829 Squared multiple R: 0.687

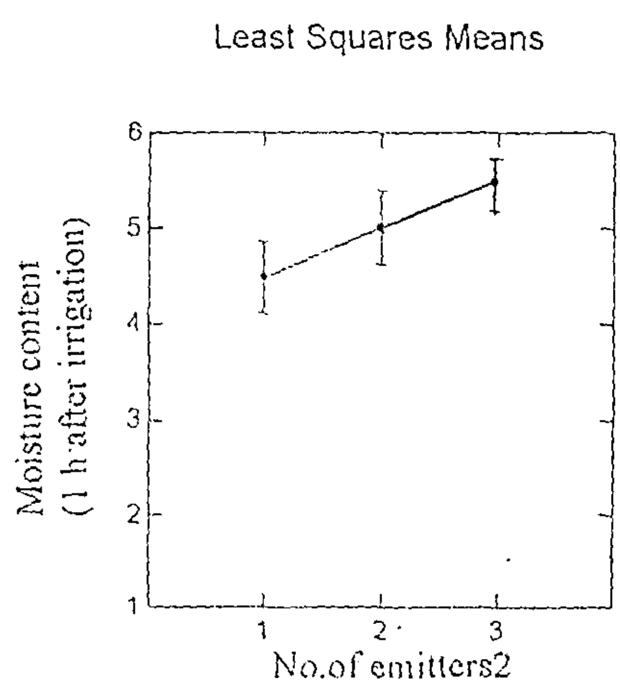
Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
DIS1	119.164	1	119.164	13.274	0.0
NOEM2	190.017	2	95.008	10.583	0.0
DEPTH3	2700.767	3	900.256	100.279	0.0
HORI4	2037.219	2	1018.609	113.462	0.0
Error	1858.354	207	8.978		

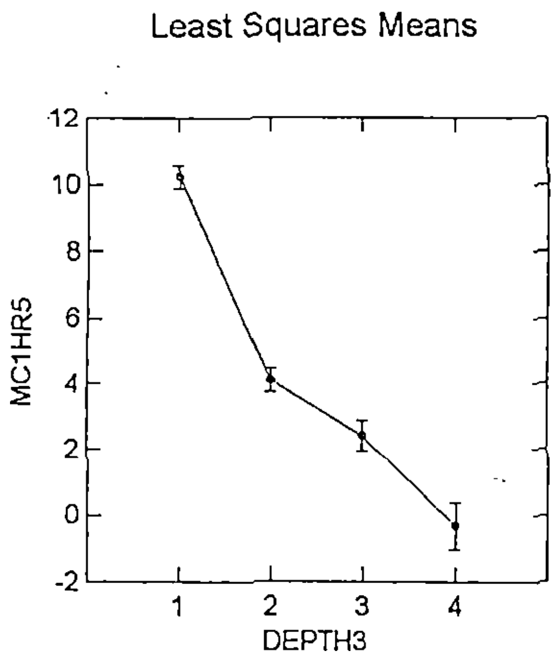
File: A:\GLM1.syo



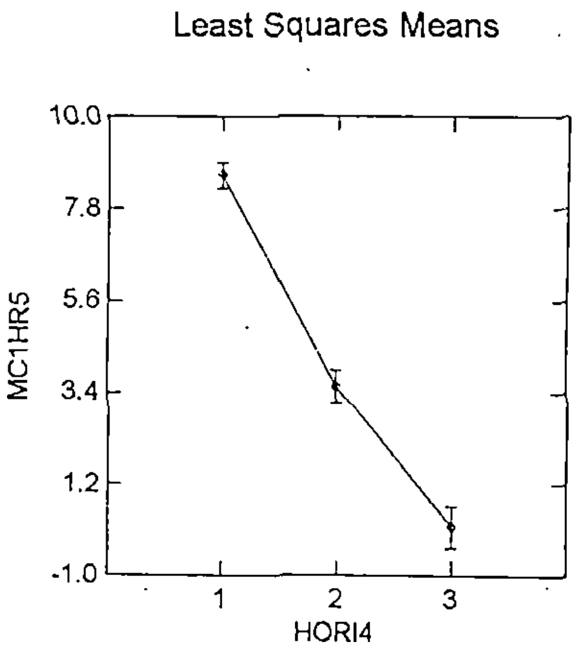
1- 4 lph
2 -8lph



1- 3 no. of emitters
2 - 4 no. of emitters
3- 6 no. of emitters



Least Squares Means
MC1HR5
DEPTH3
-2
0
2
4
6
8
10
12
1
2
3
4



Least Squares Means
MC1HR5
HORI4
-1.0
1.2
3.4
5.6
7.8
10.0
1
2
3

Durbin-Watson D Statistic 0.705
First Order Autocorrelation 0.643

Test for effect called: CONSTANT

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	2431.768	1	2431.768	270.872	0.000
Error	1858.354	207	8.978		

Test for effect called: DIS1

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	119.164	1	119.164	13.274	0.000
Error	1858.354	207	8.978		

Test for effect called: NOEM2

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	190.017	2	95.008	10.583	0.000
Error	1858.354	207	8.978		

Test for effect called: DEPTH3

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	2700.767	3	900.256	100.279	0.000
Error	1858.354	207	8.978		

Test for effect called: HORI4

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	2037.219	2	1018.609	113.462	0.000
Error	1858.354	207	8.978		

DIS1 NOEM2 DEPTH3 HORI4 MC1HR5 MC24HR6

72 case(s) deleted due to missing data.

Dep Var: MC24HR6 N: 216 Multiple R: 0.714 Squared multiple R: 0.510

Adjusted squared multiple R: 0.500 Standard error of estimate: 2.988

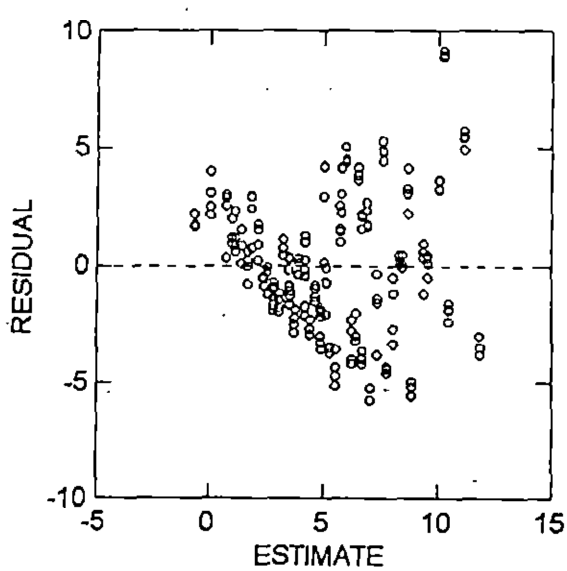
Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P(2 Tai]
CONSTANT	14.970	1.149	0.000	.	13.032	0.0C
DIS1	1.618	0.407	0.192	1.000	3.979	0.0C
NOEM2	-0.696	0.249	-0.135	1.000	-2.794	0.0C
DEPTH3	-1.796	0.223	-0.423	0.844	-8.063	0.0C
HORI4	-3.856	0.282	-0.718	0.844	-13.686	0.0C

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Regression	1958.054	4	489.514	54.819	0.000
Residual	1884.142	211	8.930		

Durbin-Watson D Statistic 0.682
First Order Autocorrelation 0.638

Plot of Residuals against Predicted Values



Test for effect called: CONSTANT

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	1516.487	1	1516.487	169.827	0.000
Error	1884.142	211	8.930		

Test for effect called: DIS1

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	141.375	1	141.375	15.832	0.000
Error	1884.142	211	8.930		

Test for effect called: NOEM2

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	69.732	1	69.732	7.809	0.004
Error	1884.142	211	8.930		

Test for effect called: DEPTH3

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	580.503	1	580.503	65.009	0.000
Error	1884.142	211	8.930		

Test for effect called: HORI4

Test of Hypothesis

Source	SS	df	MS	F	P
Hypothesis	1672.450	1	1672.450	187.293	0.000
Error	1884.142	211	8.930		

Durbin-Watson D Statistic 2.324
First Order Autocorrelation -0.164

Effects coding used for categorical variables in model.

Categorical values encountered during processing are:

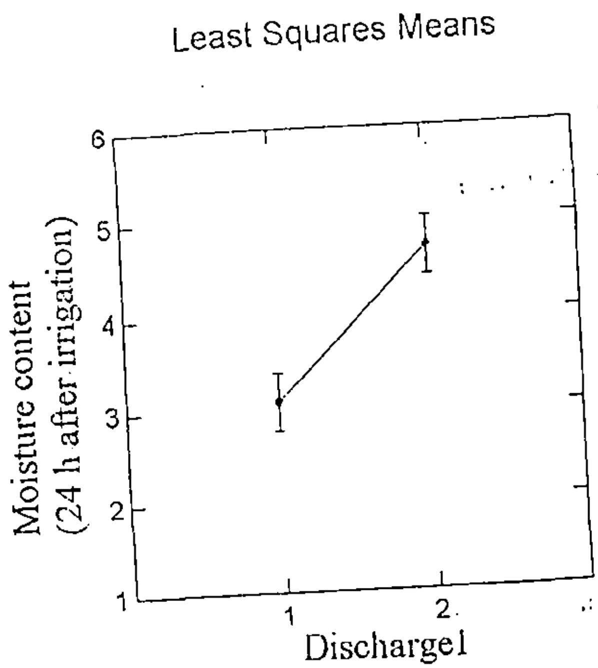
```
DIS1 (2 levels)
        1,       2
NOEM2 (3 levels)
        1,       2,       3
DEPTH3 (4 levels)
        1,       2,       3,       4
HORI4 (3 levels)
        1,       2,       3
```

72 case(s) deleted due to missing data.

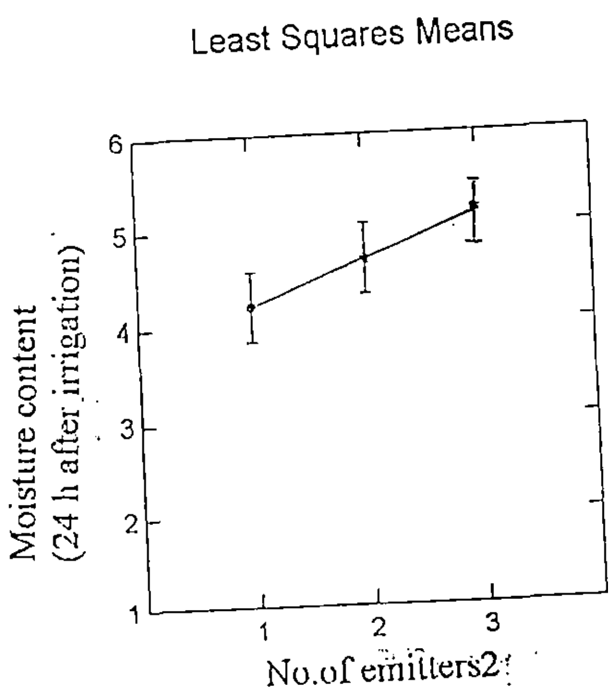
Dep Var: MC24HR6 N: 216 Multiple R: 0.743 Squared multiple R: 0.552

Analysis of Variance

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
DIS1	141.375	1	141.375	17.002	0.000
NOEM2	136.397	2	68.198	8.202	0.000
DEPTH3	591.952	3	197.317	23.730	0.000
HORI4	1630.209	2	815.104	98.025	0.000
Error	1721.254	207	8.315		

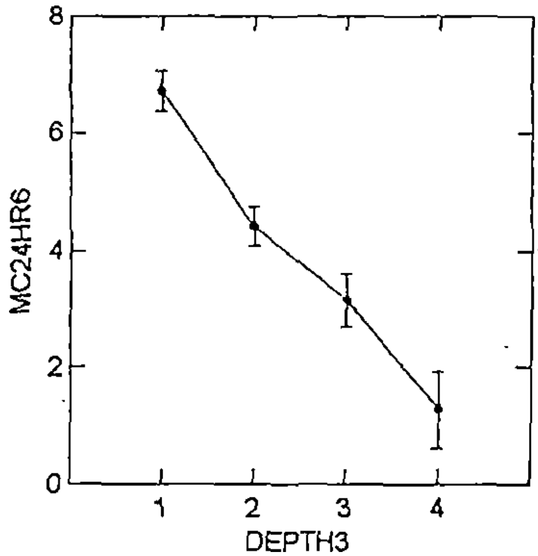


1- 4 lph
2 -8lph

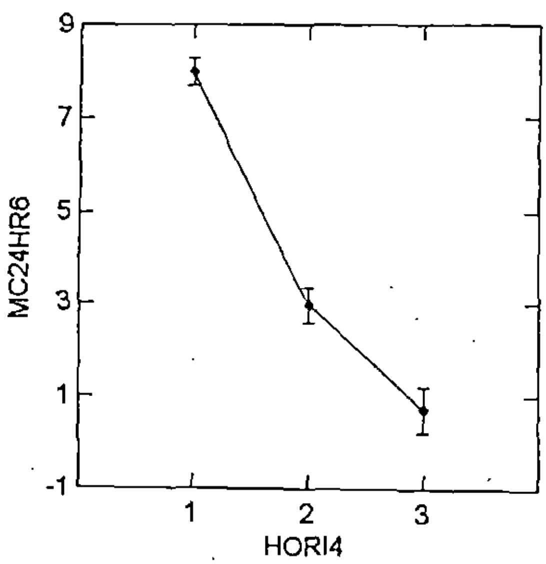


1- 3 no. of emitters
2- 4 no. of emitters
3- 6 no. of emitters

Least Squares Means



Least Squares Means



```
  1  1
  2  2
  3  3
Using least squares means.
Post Hoc test of MC24HR6

------------------------------------------------------------------------------

Using model MSE of 8.315 with 207 df.
Matrix of pairwise mean differences:

                    1           2           3
          1       0.000
          2      -5.020       0.000
          3      -7.263      -2.243       0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

                    1           2           3
          1       1.000
          2       0.000       1.000
          3       0.000       0.000       1.000
------------------------------------------------------------------------------

COL/
ROW DIS1
  1  1
  2  2
Using least squares means.
Post Hoc test of MC24HR6

------------------------------------------------------------------------------

Using model MSE of 8.315 with 207 df.
Matrix of pairwise mean differences:

                    1           2
          1       0.000
          2       1.618       0.000

Tukey HSD Multiple Comparisons.
Matrix of pairwise comparison probabilities:

                    1           2
          1       1.000
          2       0.000       1.000
------------------------------------------------------------------------------
```

Appendix V (Contd.....)

The mean distribution efficiency for different treatments at various depths for 1 hour after irrigation

Depth (cm)	T_1	T_2	T_3	T_4	T_5	T_6
15	62.86	85.93	83.38	94.65	75.15	75.3
30	65.22	88.98	86.98	96.15	70.38	71.95
60	37.51	50.31	74.16	78.2	49.85	54.54
75	38.75	52.6	65.63	76.72	41.7	44.57

The mean distribution efficiency for different treatments at various depths for 24 hour after irrigation

Depth (cm)	T_1	T_2	T_3	T_4	T_5	T_6
15	54.82	76.76	79.97	90.99	64.23	66.27
30	60.17	80.47	83.4	94.7	63.6	72.11
60	53.55	84.29	82.01	95.4	77.17	75.36
75	38.6	61.3	82.51	86.27	60.48	58.16

OPTIMAL NUMBER AND DISCHARGE RATE OF EMITTERS FOR COCONUT PALM IN SANDY LOAM SOIL

By

PRIYA G. NAIR

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Irrigation & Drainage Engineering
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR - 679 573, MALAPPURAM
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ABSTRACT

Agricultural productivity is based on the availability of required water at proper time. As water is becoming a limited resource its efficient utilization is very essential. The distribution of rainfall in Kerala is not adequate to meet the total water requirement of coconut . Coconut in Kerala are mostly grown in sandy soils which has a poor water holding capacity. So drip irrigation is the best method of irrigation for coconut in this soil. The efficient design of drip irrigation system involves the optimal spacing of emitters, correct discharge rate and duration of irrigation based on the movement of soil moisture front. So the study of moisture distribution pattern under drip irrigation is helpful in deciding optimum number and discharge rate of emitters and duration of irrigation required for coconut palms.

The study was conducted in the river side coconut garden of the instructional Farm, KCAET, Tavanur. The size of the plot was 28x63m. The soil properties viz: texture, bulk density, infiltration rate, field capacity, hydraulic conductivity and permanent wilting point were observed. The drip system was installed in the field. Two different discharge rates (4 and 8lph) and three combination of number of emitters (3,4 & 6) were selected for the study. The maximum vertical and horizontal advance of soil moisture front for both the discharge rates (4 and 8 lph) were noted. Empirical equations were also developed for both vertical and horizontal advance. The soil moisture contents were determined at different horizontal and vertical distances from the emitter, before irrigation, 1 hour, 24 hours and 3 days after irrigation by gravimetric method. The soil moisture contour maps were plotted and the moisture distribution efficiency was calculated for each treatment at all depths.

The maximum vertical and horizontal advance was observed for 8 lph emitter compared to 4 lph emitter. The wetting front from a single emitter produced a bulb like wetting pattern for both the discharges. The size of the wetting bulb increased with increase in discharge rate. The study revealed that 4 numbers of 8 lph emitters give more uniform distribution compared to all the other treatments.