EFFECT OF LANDSLOPE ON UNIFORMITY OF WATER DISTRIBUTION OF SPRINKLERS

By

JIGIMON T.

THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology

KERALA AGRICULTURAL UNIVERSITY

Department of Land and Water Resources & Conservation Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679 573

MALAPPURAM

1996

DECLARATION

I hereby declare that this thesis entitled **"Effect of land slope on uniformity of water distribution of sprinklers"** is a bonafide record of work done by me during the course of research and this 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.

Tavanur
8-5-96

JIGIMON, T.

CERTIFICATE

Certified that this thesis entitled **"Effect of land slope on uniformity of water distribution of sprinklers"** is a record of original work done independently by **Sri. Jigimon T.** under my guidence and supervision and that it has not previously formed the basis for any degree, diploma, fellowship or associateship to him.

Dr. Jobi V. Paul
Chairman, Advisory Committee
Associate Professor
Department of Land and Water Resources
and Consevation Engineering
K C A E T, Tavanur

CERTIFICATE

We, the undersigned members of the Advisory Committe of **Sri. Jigimon T.**, a candidate for the degree of Master of Technology in Agricultural Engineering with major in Soil and Water Engineering, agree that the thesis entitled **"Effect of land slope on uniformity of water distribution of sprinklers"** may be submitted by Sri. Jigimon T., in partial fulfilment of the requirement for the degree.

Dr. Jobi V. Paul
(Chairman, Advisory Committee)
Associate Professor
Department of Land and Water Resources
and Conservation Engineering
K C A E T, Tavanur

Dr. K. John Thomas
Dean
K C A E T, Tavanur
(Member)

Dr. Habeebur Rahman
Assistant Professor
Department of SAC
K C A E T, Tavanur
(Member)

Er. Alexander Seth
Assistant Professor
Department of IDE
K C A E T, Tavanur
(Member)

External Examiner

ACKNOWLEDGEMENT

I sincierly express my whole hearted gratitude, indebtness and respect to **Dr. Jobi V. Paul**, Associate Professor, Department of Land and Water Resources and Conservation Engineering, KCAET, Tavanur and Chairman of Advisory Committee, for his valuable guidance, critical suggestions and immense help throughout the course of work and inseparation of this thesis work.

I am immensly grateful to **Dr. K. John Thomas**, Dean, KCAET, Tavanur, **Dr. Habeebur Rahman**, Assistant Professor, Department of Supportive and Allied Courses and **Er. Alexander Seth**, Assistant Professor, Department of Irrigation and Drainage Engineering, members of the Advisory Committee for their sustained interest and advices extended to me to complete this endeavour.

I gratefully appreciate the co-operation received from **Dr. K.I. Koshy**, Professor and Head of the Department of SAC, and **Miss Beena, G.**, Junior Programmer, Computer Centre, KCAET, Tavanur, for permitting me to avail the facilities of the computer centre during the analysis of the data.

I am thankful to **Er. Noble Abraham**, Assistant Professor, Department of LWRCE, **Er. P. Rajendran**, Assistant Professor, Department of SAC and **Er. E. K. Kurien**, Assistant Professor, Department of LWRCE for providing me the necessary fqcilities and materials for establishing the turf at the site.

With immense pleasure and deep sense of gratitude I acknowledge all the valuable help rendered to me by all the staff members and friends for their enthusiastic support during the course of my work.

At this moment I thankfully remember the blessings of my loving family for their stable support throughout the work.

And, last but not the least, I bow my head before that all prevading sublime power which showed me my path throughout.

Tavanur **JIGIMON, T.**

To My Loving Mother

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

Agric	-	Agricultural
ASAE	-	American Society of Agricultural Engineers
ASCE	-	American Society of Civil Engineers
cm	-	centi meters
Co.	-	Company
Cu	-	Coefficient of uniformity
D	-	Dimensional
Dr.	-	Doctor
et al.	-	and others
Engg.	-	Engineering
Fig.	-	Figure
F T A	-	female threaded adaptor
G I	-	galvanised iron
ha	-	hectares
H P	-	horse power
I B H	-	India book house
I & D	-	Irrigation and Drainage
I S A E	-	Indian Society of Agricultural Engineers
J.	-	Journal
K C A E T	-	Kelappaji College of Agricultural Engineering and Technology
Kg/cm^2	-	Kilograms per square centimeter
Kmph	-	Kilometers per hour
Kpa	-	Kilo pascal
lit./sec	-	litres per second

lit./min	-	litres per minute
L P	-	Linear Programming
Ltd.	-	Limited
mm	-	milli metres
max	-	maximum
mm/hr	-	milli metres per hour
m/s	-	metres per second
Mha	-	Million hectares
M T A	-	Male threaded adaptor
NH_4NO_3	-	Ammonium nitrate
No.	-	Number
psi.	-	pounds per square inch
PVC	-	poly vinyl chloride
Pvt.	-	Private
Q	-	Quintal
rpm	-	rotations per minute
Sci.	-	Science
Soc.	-	Society
U S A	-	United States of America
V	-	Volt
var	-	variation
viz	-	namely
&	-	and
/	-	bar
%	-	percentage
'	-	minutes
''	-	seconds
°	-	degrees

Introduction

INTRODUCTION

Irrigation is defined as `the application of water by human agency to assist the growth of crops, grasses, trees etc'. It increases the crop yields by generating a conducive environment for the high yielding variety seeds, along with the use of costly fertilizer and improved management practices. Irrigation is not mere application of water to the land, but it involves the supplying of water to the root zone of plant. Irrigation water is an expensive input and therefore its judicious use is essential. In order to determine the amount of water to be applied in a particular field, we must have a thorough knowledge about the soil, the plant and its environment. Here emerges the importance of conservation irrigation, which results in high production with less wastage of soil and water.

From time immemorial, surface irrigation methods have been followed in agriculture. The different types of surface irrigation practices are uncontrolled flooding, border irrigation, check basins, furrow and basin methods. Almost all of these methods require precise land levelling. About 45 to 65 per cent of the irrigation water is lost due to seepage and runoff in these methods. Other drawback is low aeration due to flooding. The regulation and control of water is not possible to give the required quantity of water at the root zone. To overcome these problems and to manage efficiently the water input, new irrigation techniques have been developed. Among this sprinkler irrigation and drip irrigation are versatile means of applying water to any crop, soil and topographic condition. They are known for water saving and uniform application of measured quantity of water.

Sprinkler irrigation is an irrigation system that tends to simulate the rainfall. In this method the runoff and deep percolation losses are minimum. The uniformity of application is made as close to as would be obtained under rainfall conditions. In this system, water under pressure is forced through nozzles of small diameter. It is possible to attain high irrigation efficiency using sprinkler method which is not generally obtained under surface irrigation methods. It can be used to a wide variety of crops.

Soils which are too shallow to be levelled properly for surface application methods can be irrigated safely by sprinklers. Land levelling is not essential for irrigation with sprinklers. However, grading is advisable if surface drainage is a problem or a more uniform surface is needed for seeding, tilling and harvesting. Soluble fertilizers and fungicides can be applied in the irrigation water with little extra equipment. More land availability for cultivation and permission for movement of farm machinery are some of its plus points.

The flexibility of sprinkler equipment and its efficient control of water application makes this method adaptable to most topographic conditions without extensive land preparation. If soil erosion is a hazard, sprinkler irrigation can be used in conjunction with contour bunding, terracing, mul ching and stripping. Sprinkler irrigation is very popular in the country especially in hills for plantation crops, forest nursery and winter vegetables. It is suitable for steep slopes or irregular topography. Land too steep for efficient irrigation by other methods can be irrigated using sprinklers safely. It is best suited for plantation crops such as tea, coffee and cardamom during dry session to overcome shortage of water. The method can be adopted effectively to other crops such as pulses, oil seeds, cotton, sugarcane and vegetables in hilly areas. Sprinkler irrigation is very well suited to all closely spaced crops. Manifestation of water crisis assumes gigantic propositions particularly during summer season over a sizeable parts of India especially in hilly areas or sloping lands. It is here that sprinkler irrigation opens opportunities for a fairly expanded operation to the Indian farmers, to surmount the various problems and constraints.

The efficiency of any sprinkler system is determined by the uniformity of water distribution by the sprinklers. The sprinkler distribution efficiency is highly correlated to the spacing of sprinklers on laterals and laterals in turn on mains. Besides it is also influenced by the orientation and nature of the single sprinkler pattern. The riser angle and nozzle angle are having a very important role in uniform water distribution in sloping lands. The spray distribution characteristics of sprinkler heads are typical and vary with the nozzle size. The rotation rate of sprinkler will vary with respect to the riser position. Wind is another factor which distorts the application pattern. The higher the wind velocity the greater will be the distortion. The operating pressure also has an important role in proper water distribution of sprinklers. A higher or lower operating pressure is not favourable. In sloping lands the sprinkler irrigation may cause soil erosion. It depends upon the type of soil and the position of riser pipe.

The general objective of the present study was to study the effect of land slope on sprinkler uniformity. The specific objectives are:

1) To study the sprinkler rotation rate when the sprinkler riser is not in the vertical position.

2) To study the effect of sprinkler riser angle on uniformity.

3) To study the effect of wind on uniformity of water distribution.

4) To propose an optimum riser angle for uniform water distribution and minimum erosion risk for sloping terrain.

Review of Literature

REVIEW OF LITERATURE

The demand of water is increasing day by day for all purposes. The future needs can be succesfully met by proper planning, development and efficient use of water. The amount as well as timing of rainfall are not sufficient for the crop water requirement in most of the areas of the world. Therefore a rapid expansion of irrigation is necessary for the additional food production. The old methods of irrigation have to be oriented towards bringing more area under irrigation from the available water. Sprinkler irrigation is a modern scientific irrigation system that can be practiced to obtain highest productivity with minimum water and least disturbance to the ecosystem. This is one of the most widely used irrigation methods on sloping lands. Uniformity of water distribution, good application efficiency, limited erosion, relatively low labour requirement and the practicality of use on various soils and for uneven topographic conditions are attributes that make sprinkler irrigation attractive.

2.1 Sprinkler irrigation

Sprinkler irrigation came into existence more than 70 years ago in the United States and other advanced countries. But its large scale development did not get underway till about the year 1946. Since then there had been a tremendous development in the field, particularly in the western countries. A detailed review of the work done by earlier researchers and the various features of sprinkler irrigation system are presented in this chapter.

2.1.1 Development of sprinkler irrigation

Sprinkler irrigation was developed in the year 1900. It appears that in the year 1967, about 2.6Mha were irrigated with sprinkler in Europe. At the end of the year 1967, there was about 3.0Mha irrigated with sprinklers in the USA, representing about 17 per cent of the total irrigated area (Sivanappan, 1987). In Israel 0.15Mha representing about 95 per cent of the total irrigated area was by sprinklers. Experimental units were installed in Taiwan in the year 1952 for irrigating sugarcane with encouraging results. Sprinkler irrigation was introduced in Australia for orchards and for fodder crops in about 50,000ha. It was estimated in the year 1970, that sprinkler irrigation was adopted in an area of about 6.0Mha in the world.

Sprinkler irrigation was not familiar in India till the year 1980. In early years, plantation farmers used sprinklers for irrigating their coffee, tea, cardamom and other crops raised on sloping hills as supplemental irrigation during non-rainy periods which enhanced the crop yield. The gross area under sprinkler irrigation is about 0.23Mha in India out of the total irrigated area of about 71.32Mha. Indigenous manufacture of the system started about 20 years ago using foreign design and technology. Galvanised steel pipes are more popular than aluminium pipes as they are stronger and available at a lower cost to the farmer. Various schemes with subsidy of the Central and State Governments are helping to popularise the sprinkler system among the farmers.

2.2 Components of sprinkler system.

2.2.1 Pumping unit.

Sprinkler irrigation system distributes water by spraying it over the fields. The water is pumped under pressure to the fields. The pressure forces the water through sprinkler nozzle or through perforations in pipe lines and spray is formed. Sometimes the slope of the land is sufficient to provide gravity pressure in pipe line. A high speed centrifugal or turbine pump can be installed to provide necessary power for operating the system on individual farmholdings (Michael,1978; Sivanappan, 1987). The pumping plant usually consists of a centrifugal or turbine pump, a driving unit, a suction line and foot valve. A centrifugal pump is used when the distance from the pump inlet to water surface is less than 8 meters, otherwise a turbine pump is recommended. The driving unit may be either an electric motor or an internal combustion engine.

2.2.2 Main line

The main line is a pipe which delivers water from the pump to the laterals. In some cases the main line is permanent and is laid in the field either above or, more usually, below the ground. In others it is portable and can be moved from field to field (Kay Melvyn, 1983). Steel pipes are used for most of the permanent main lines. Asbestos, cement and PVC pipes are also used but concrete pipe lines are not adopted in high pressure sprinkler system. The permanent lines should be buried so as to be out of the way of farming operations. Light weight aluminium pipes with quick couplers are used for most of the portable main lines (Micheal, 1978).

2.2.3 Submains

The submains are those pipe lines which are fed into the irrigated fields and supply water to the risers through sprinkler laterals and valves spaced at regular intervals. The submains are usually of steel or asbestos, cement or PVC. They are laid usually along the boundaries of the irrigated plots, but in some cases they are run along the centre line of the fields (Herman J. Finkel, 1982).

2.2.4 Sprinkler laterals

The laterals convey the water, through suitable couplings and risers, spaced at regular intervals, to the sprinklers.

The sprinkler laterals are generally of aluminium and they can be transported from one position to another at the end of an irrigation period. Polyethelene pipes or PVC pipes are also being used as stationary as well as portable laterals (Herman J. Finkel, 1982).

2.2.5 Risers

Risersare small diameter pipes which connect the sprinkler heads to the laterals. Pipes with diameter ranging from 12mm to 25mm are used depending upon the size of the sprinkler (Kay Melvyn, 1984). Risers are normally connected to the lateral with a pipe coupler. Connections are made using stand and pipe screw threads. The height ofthe riser is chosen as to allow the sprinkler to operate above the crop canopy (Michael, 1978).

2.2.6 Sprinkler heads

The sprinkler head is the most important component of a sprinkler irrigation system. Its operating characteristics, suitability and efficiency under optimum water pressure and climatic conditions are mainly determined by the wind velocity (Michael, 1978). The rotating type sprinkler heads are generally used and can be adopted for a wide range of application rates and spacings. They are effective with a pressure of about 10m to 70m head at the sprinkler. Pressure ranging from 16m to 40m head are considered as the most practical one for most of the farms (Sivanappan, 1987). Fixed head sprinklers are commonly used to irrigate small lawns and gardens.

2.3 Advantageous of sprinkler system

2.3.1 Water conservation

Considerable amount of water saving can be achieved by adopting sprinkler irrigation, compared to surface methods.

The report by the Haryana Irrigation Department (Sivanappan, 1987) says that saving of water by sprinkler was 56 per cent compared to surface methods in the case of wheat, jowar, barley, bajra and gram and was 29 per cent in the case of cotton. The Punjab Agricultural University has reported (Sivanappan, 1987) a water saving of 42.7 per cent for wheat and 47.5 per cent for maize. The University of Agricultural Sciences, Bangalore, has found that the net irrigated area and cropping intensity were higher when sprinkler irrigation was introduced in the university farm.

A comparative study on sprinkler irrigation in respect of cotton was undertaken with the basin method of irrigation at Coimbatore. The cotton yield was the highest under sprinkler irrigation (22.3Q per ha) consuming only 316mm of water where as the basin system recorded the lowest yield of 18.5Q per ha consuming the largest quantity of water (610mm) (Sivanappan, 1987). Comparative studies on sprinkler and surface irrigations done at Madurai, revealed that sprinkler irrigation was preferable for both yield betterment and water saving in case of groundnut.

Christiansen (1942) has estimated that direct evaporation from the spray itself, when normal pressure is applied in a normal wind velocity condition, did not exceed 2 per cent. Dev Nir (1982) reported that in green houses, sprinkling not only provides water, but also regulate air humidity, temperature etc. Gueorguiev *et al.* (1988) did a study on sprinkler irrigation for rice for three years in Plovdiv and Ivalo, Bulgaria. The sprinkler system achieved a 67 per cent saving in water applied for the cost of a 10 per cent drop in yields.

Richard *et al.* (1986) developed a linear programming (LP) frame work with associated design and cost estimating procedures to evaluate the economics of deficit irrigation in sprinkler system design and optimize the system components. The modelling procedure is useful for planning irrigation development or management in water short areas.

2.3.2 Irrigation efficiency

In sprinkler system no conveyance losses occurs since water is delivered through pipes. Irrigation efficiency is therefore the application efficiency which is expressed as the ratio of the amount of water applied to the rootzone to the amount discharged by sprinklers. This varies from 60 per cent to 70 per cent depending on evaporation losses and management of the system (Sivanappan, 1987).

Trimmel *et al.* (1987) reported that the two centre pivot irrigation systems in North Central Oregon, USA were monitored using irrigation techniques to determine the efficiency of water application. The efficiency was defined as the ratio of the calculated net irrigation to gross water applied as measured with a flow meter. Overall efficiency was found to be greater than 90 per cent.

Tsakiris *et al.* (1985) developed a Pearson distribution model describing the sprinkler irrigation efficiency. A Pearson type III distribution model was used to simulate water distribution from rotating sprinklers. Using an analytical-numerical approach, graphs were constructed for easy calculation of the performance parameters such as adequated irrigated area, mean deficit and deep percolation efficiency. In order to achieve this, the coefficient of skewness was assumed to be a constant multiple of the coefficient of variation. Thus the Pearson type III distribution parameters were expressed as the function of coefficient of variation.

Ronald *et al.* (1980) studied the fitting of linear, normal and beta statistical models to over lap sprinkler pattern data. They reported that for the calculation of water volumes which are needed in the determination of irrigation efficiencies, the normal and linear models are at present more practical to use than the beta distribution. However, if tables, or equations, or both are developed for readily determining the irrigation performance parameters from the beta distribution, then this greater accuracy could warrant its use. At the uniformity coefficient values most commonly encountered in the design and evaluation of sprinkler system, the normal model is recommended over the linear model for the calculation of irrigation efficiencies.

2.3.3 Soil conservation

Sprinkler irrigation can be used profitably, in almost all types of soil. With this method there will not be any soil erosion problem, also no compaction of soil during irrigation, land levelling is not necessary, no land being lost for ditch formation as in the case of surface irrigation and it will control leaching of salts. On the whole, it appears that the effect of properly applied sprinkler irrigation is not harmful to the soil and some ways it is more beneficial than surface irrigation (Sivanappan, 1987).

Cook (1983) conducted studies on water distribution over the soil surface and within the soil during sprinkler irrigation. Distribution of water in the soil at times during and following irrigation with a `big gun' sprinkler irrigator was studied. The depth of water that had infiltrated the soil varied greatly and did not relate well to that applied at the sampling site. Surface ponding of water and runoff into micro-topographical depressions had occured, causing highly variable wetting pattern found in the soil as application rate is more than infiltration rate.

2.3.4 Crop benefits

Soil moisture is maintained at optimum level by sprinkler irrigation and so higher yields are obtained in some crops. The quality of the product is also good. It helps in providing the frost protection. Since the water is sprayed over the crops, it permits cooling of crops. In this system fertilizers and pesticides can be mixed with water and applied, and hence the efficiency of these inputs for better crop production is more when compared to the surface irrigation methods (Sivanappan, 1987).

Sanchez *et al.* (1994) conducted six field studies from the year 1980 to the year 1988 to evaluate the response of cabbages to sprinkler irrigation and sprinkler applied nitrogen fertilizer on a coarse textured soil. The plots were irrigated using a modified self-moving lateral sprinkler irrigation system that applied 5 levels of water and 5 levels of nitrogen (liquid NH_4NO_3) in specified combinations of central composite rotatable design. Cabbage yields were significantly increased by water and nitrogen applications in all experiments. Deficit and excess irrigation produce negative results. Generally, cabbage production was optimized and nitrogen losses to the environment was minimized when crops were irrigated for evapotranspiration.

Ayars *et al.* (1993) reported the influence of cotton canopy on sprinkler irrigation uniformity. A growing crop canopy has a significant potential to modify the distribution of water applied during an irrigation. The results of the study demonstrated that a cotton canopy tends to improve the uniformity coefficient under certain circumstances. As the individual depth of application is increased the effect of the uniformity coefficient being improved by the canopy is reduced. For the system with a good design uniformity (>90 per cent), the depth of application did not affect the uniformity coefficient below the canopy. Measuremnt of the uniformity coefficient on individual dates during the irrigation season will tend to underestimate the cumulative uniformity coefficient.

2.3.5 Labour benefit

Sprinkler irrigation is automated and since the lateral pipes are shifted once in six or eight hours, it reduces labour requirements. But where the land and farm distribution system are unusually well adopted to the surface methods, labour cost may be much less than with the sprinkler system.

Fertilizers can also be applied through this system which saves labour. This system pays for itself in a few seasons when developing new land, and it may well be less expensive than the surface method, since land leveller is not essential and construction of channels is not needed (Sivanappan, 1987).

2.4 Sprinkler head classification

2.4.1 Sprinkler heads mounted on a riser

In this category, sprinklers are connected at the top of the risers equi-distant along the sprinkler lateral. The water distribution pattern of most sprinklers are characteristically triangular. All the nozzles will convert the pressure head into velocity head, giving the water jet its initial velocity. The combination of pressure head and nozzle diameter determines the intensity of drop formation and the distribution over the wetted area.

2.4.1.1 Revolving sprinklers

These sprinklers are operated by a hammer which acts horizontally around a vertical pivot and is regulated by a spring. Regular hammer and wedge hammer are common types of hammers used.

The striking jet produces a horizontal component in case of regular hammer, perpendicular to the driving head. Here the hammer is forced to rotate in the direction, as far as the spring would allow it. The hammer returns to its initial position by a counter moment. At this stage the rotating hammer strikes the body of the sprinkler causing it to rotate. This process will continue time after time.

2.4.1.1.1 Conventional/Small sprinklers

They are mounted on riser pipes or on posts above the crop height and rotated through 90 degrees to irrigate a rectangular strip. The sprinkler operates at low to medium pressure of 2 bars to 4 bars and can irrigate an area 9.24m wide and upto 300m long at one setting. Application rates vary from 5 mm/hr to 35 mm/hr.

2.4.1.1.2 Boom type/Self propelled sprinkler system

In this type each lateral has one boom sprinkler, which is a nozzled, slowly rotating pipe line that suspends from a portable tower. Tractor or winch is used for moving boom sprinklers from one position to another by towing along the laterals. The width of irrigation is 75m to 100m depending on nozzle size and pressure. These are useful for tall crops like sugarcane and corn.

A self propelled sprinkler consists of a radial pipe line supported at a height of 1.8m to 2.4m at intervals of about 30m on towers mounted on two wheels or a small truck. A radial line is rotated slowly around the first point in the centre of the field by either water pressure actuaters or by electrical motors at each tower. Conventional sprinklers mounted on the pipe, then distribute water to the field as the pipe line is moving. This system covers about 10ha to 100ha and the total capacity ranges from 1500 lit./min to 4500 lit./min. These type of sprinklers is often used for crops where it is difficult to move sprinkler laterals in conventional manner (Sivanappan, 1987).

2.4.1.2 Whirling sprinklers

These sprinklers are simple and sturdily constructed. They have either two or three long arms at the ends of which are the nozzles. Rotation is produced by aeration force, resulting from the ejecting jet. A whirling sprinkler wets a circular area without wind, which are bored in the upper half of the tubing surface. The number of holes, their arrangement and their diameter combine to fix the characteristics of a particular perforated pipe.

2.4.2.2 Oscillating rain pipe

In this type of sprinkling, pipes supported on stationary or portable posts, turns back and forth around its horizontal axis. Operation is caused by an oscillator. The water flows out through nozzles, inserted at regular intervals along the top of the pipe. The oscillator is operated by the pressure of the water (Herman J. Finkel, 1982).

2.5 Types of sprinkler systems

2.5.1 Portable system

This system consists of portable main lines and laterals and a portable pumping plant. It therefore enables the movement from field to field or between different pump sites in the same field. Manual or mechanical power can be used for the movement. The initial investment of land move system on sprinkler unit is not high but the labour cost is more. In wheel move system, the laterals are mounted as a unit instead of one pipe at a time. Here capital investment is more but, labour cost is less (Michael, 1978).

2.5.2 Semi portable system

A semi portable system is similar to a fully portable system except that the location of water source and pumping plant are fixed. Such a system may be used for more than one field where there is an extended main line, but may not be used on more than one farm unless there are additional pumping plants (Michael, 1978).

2.5.3 Semi permanent system

A semi permanent system has portable lateral lines, permanent mainlins and submains, and a stationary water source and pumping plant. The main lines and submains are usually buried, with risers for nozzles located at suitable intervals (Michael, 1978).

2.5.4 Solid set system

A solid set system has enough laterals to eliminate their movement. The laterals are positioned in the field early in the crop season and remain for the season. The system is used for places requiring short and frequent irrigation (Michael, 1978).

2.5.5 Permanent system

A fully permanent system consists of permanently laid mains, submains and laterals, usually buried below plough depth. Sprinklers are permanently located on each riser. Such systems are suited to automation of the system with moisture sensing devices. In orchards usually permanent type sprinkler system is used (Michael, 1978).

2.6 System performance

English *et al.* (1986) conducted studies for evaluating sprinkler system performance. A computer model of sprinkler system performance was devoloped to estimate more precisely the efficiency of the irrigation system. The model estimates gross water requirements, wind and evaporation losses, runoff and re-distribution of ponded surface water, deep percolation, evaporation and crop yields. It accounts for special variability of soil properties and sprinkler patterns and allows the use of select alternate algorithms for estimating infiltration rate and sprinkler water loss. Alternative definitions of efficiency are also discussed.

Richard (1986) developed a linear programming (LP) frame work with associated design cost-estimating procedure to evaluate the economics of deficit irrigation in system design and to optimize the sizing and operation of irrigation system components. The frame work includes linear evapotranspiration, crop production functions and simulates crop evapotranspiration and crop yields according to irrigation application levels and soil moisture availability. The LP frame work considers and accounts for costs for capital, labour, energy and water and provides for hydraulic and economic continuity throughout the system. Sprinkler, pipe,pump,canal and soil systems are simulated and total system productivity and profitability are determined.

2.6.1 Radius of throw

Dennis (1982) developed a mathematical relationship describing the combined effects of nozzle size, pressure and nozzle discharge on sprinkler pattern radius. The nozzle jet momentum flux was found to be a significant factor in pattern radius. A power function is used to relate the momentum parameter to pattern radius. The relationship was evaluated by the use of manufactures catalog data and laboratory pattern test data collected at Kimberly. The relationship can be used in computer simulation of sprinkler systems to predict variations in pattern radius with pressure variation due to topography and friction losses. One method can also be used to compare the perfomance of different sprinklers or nozzles and to determine the effect of variables such as nozzle height or jet angle on pattern radius.

It was hypothesized that the effects of pressure, discharge and nozzle size on the pattern radius could be combined in one parameter proportional to the jet momentum flux ie;

$$R = f\ (q,v)$$

where

R = pattern radius

q = nozzle discharge

v = jet velocity

In order to test the pattern radius relationship independent of catalog data a series of indoor sprinkler tests were conducted at the Snake River Conservation Research Centre, Kimberly. Ten collecters were placed at 0.5m intervals. The application rate was plotted for each test and the radius was determined at the point of intersection of the rate pattern with the above specified rate. The base pressure was measured volumetrically.

Pair (1968) studied the water distribution under sprinkler irrigation. He reported that multiple irrigations by handmove portable sprinkler laterals gave acceptable seasonal water distribution as measured by Christiansen coefficient of uniformity, eventhough some individual irrigation yielded poor water distribution. If water distribution on the first irrigation of a crop is a critical factor in better crop products, better results are obtained by applying half the water in one irrigation and half in a second irrigation if wind conditions prevail. Straight lateral, self propelled sprinkler systems gave better water distribution for individual irrigations than handmove or carriage with trailer line systems when all factors were the same. Poor water distribution resulted from water movement on the soil surface due to the sprinkler system applying water faster than the soil can absorb it. This was caused by poor system design, wind speeds or machinery compaction of soil in parts of the irrigated area.

Kincard (1991) has suggested methods of modifying the water distribution pattern of an impact drive sprinkler. A method of pattern modification called intermittent diffusion is introduced. A deflector attached to the drive arm intermittently diffuses the jet of a standard circular - orifice nozzle, producing desirable pattern shapes while maintaining a large pattern radius. Uniformity of application for both wind and no wind condition was evaluated using both the deflector and diffuse type nozzles. The deflector is beneficial for low pressure sprinkler particularly under wind conditions. Equations were developed to predict the operating characteristics of the impact arm.

Seginer *et al.* (1992) conducted studies on indoor measurement of single radius. An automatic apparatus for measuring single radius sprinkler distribution pattern was designed and constructed. Any number of consecutive trials with different operating pressures and riser tilts could be conducted automatically. Water heights in the precipitation gauges were measured sequentially, utilizing a single pressure transducer. Computer controlled solenoid valves were used to connect gauges to the transducer and to drain the system.

2.6.2 Droplet size

Water droplet size distribution is an important consideration in the design of sprinkler irrigation systems.

Small drops lead to distortion of the spray pattern by wind. Large droplets may lead to a reduced water infiltration rate because of soil surface disruption caused by impact of droplets.

Bernuth (1984) reported that droplet size distribution data from agricultural sprinklers were useful for predicting evaporation, wind drift, and droplet effects on the soil. Collecting droplet size distribution data is tedious and expensive. So a method of estimating such data from existing or routinely connected data would be useful. The theory and technique for estimating such data using a droplet ballastics were described whereby droplet size data can be estimated from routinely collected single leg data. The model was tested for five sets of conditions including three nozzle sizes and three pressures and provided to fit published droplet size data very well. The distribution produced by the estimation techniques were presented.

Li *et al.* (1994) conducted studies on droplet size distribution from different shaped sprinkler nozzles. Droplet sizes and water distribution for two types of square nozzle and rectangular nozzle were compared with the performance of circular nozzles. Generally, volume mean droplet sizes were larger for non circular nozzles at a given distance from the sprinkler; but circular nozzles produced the largest average droplet size at the outer perimeter of their pattern. Non circular nozzles produced a much greater portion of droplets with diameter less than 3mm than circular with similar discharge at a given pressure. Non circular nozzles have the advantage of providing an acceptable water application pattern and a smaller portion of the larger droplets over the entire precipitation profile at low pressure. An experimental model to present droplet size distribution for both the circular and the non circular nozzles was developed and compared with the upper limit lognormal (ULLN) distribution model. It was verified that both models represent the droplet size distribution from circular and non circular nozzles quite well, however the exponential model was much simpler than the ULLN model.

Jaur chang *et al* (1993) studied the sprinkler droplet effects on infiltration. They reported that, droplet impact angle and water layer on the surface, each have a significant effect on the resulting peak impact pressure, impact force and shear velocity. Droplet of similar sizes and impact velocity but different impact angles (90°, 60° and 45°) or impact surface conditions (bare surface or surface with water layer 6 mm deep) generate different impact forces and lateral shear flows. Compared to a vertical droplet impact, oblique droplet impact has the effect of decreasing the magnitude of impact pressure and vertical impact forces; however the peak shear velocity is greater. The peak shear velocity from a droplet impacting a bare surface at a 60° impact angle is 1.49 times greater than that of a similar impact at 90° impact angle. A water layer on the impact surface lowers the peak impact pressure and shear velocity for all droplet impact angles but raises the impact force.

Seginer (1965) estimated the tangential velocity of sprinkler drops. It was shown that the tangential velocity of drops propelled in to the air with an upward velocity component must pass through a minimum. A graphic method of motion was outlined and analytical solutions of some simple cases were presented. Finally it was shown that experimental data and calculated solutions were in fairly good agreement when a constant drag coefficient was assumed. The methods presented may be used to impact velocity of single drops under various initial conditions.

Dadiao *et al.* (1984) compared droplet sizes and water application uniformly for aquare, double rectangular and triangular nozzles with the perfomance of circular nozzles of similar characteristics. The inverse relation between jet velocity and droplet size for circular nozzles extended to noncircular nozzles but the proportionality was not the same as for circular nozzles. The soil damage due to large droplets was further compounded by the high water application rate, near the perimeter (doughnut pattern), for circular nozzles operated at low pressures. Square and triangular nozzles produced doughnut patterns only at the lowest pressure tested, 138 KPa (20 psi).

2.6.3 Uniformity

The irrigation efficiency of sprinklers will depend upon the degree of uniformity of water application. The spray distribution characteristics of sprinkler heads are typical and change with the nozzle size and operating pressure. With lower pressure the drops are larger and the water from the nozzles fall in a ring away from the sprinkler. With higher pressure the water from the nozzles break up into very fine drops and fall very near the sprinkler (Michael, 1978). Uniformity can be improved by putting the sprinklers much closer together but this may lead to problems of higher water application rates. The number of sprinklers used also increases, raising the cost of the system (Kay Melvyn, 1983).

The uniformity of distribution from a stationary sprinkler system can be tested in the field. To do this several small cans are placed in a square grid between the sprinklers. The system is then operated for a typical irrigation set time and water is collected in the cans. By measuring the depth of the water in each cans it is possible to see how uniform the irrigation is. Uniformity of distribution for a mobile system can be tested by setting a line of cans across the travel path of the machine (Kay Malvyn, 1983).

Cook (1983) conducted a study about water distribution over the soil surface and within the soil during sprinkler irrigation. Twelve plastic containers (top area of $26.2*10^4$ mm^2) were arranged in a grid pattern on the experimental area of 50m* 50m. Prior to irrigation, water content of soil is found. Irrigation is given for 45 minutes. Water content of soil is again measured. This procedure is giving a total irrigation time of 180 minutes. The volume of water applied in a single pass over the soil surface by the foot print (the rate at which water is applied to that particular instant) was also measured. Christiansens coefficient of uniformity is calculated. The time of passage of foot print over a point on the soil surface during one sweep of the big gun is 20 seconds. During this time, 3mm - 5mm of water is applied to the soil surface, equivalent to an average rate of 630 mm/hr. This rate is much greater than infiltration rate of water into the soil.

Williardson *et al.* (1986) developed a method for evaluating data from can catch tests for single sprinklers to determine the suitability of particular sprinklers for use in a line source application. The water application patterns of different commercially available sprinklers were determined by collecting can catch data using 5cm diameter plastic cups placed at 60cm intervals on four 5cm long radial lines 90cm apart. The sprinklers were tested at 0.5m, 1.0m and 1.5m heights above the ground and at pressure 20psi, 30psi and 40 psi. All tests were conducted under windless conditions. Large variations exist in the precipitation patterns for different sprinklers. The design of the nozzle affects the water distribution pattern and therefore the applicability of the sprinkler system.

Yasin *et al.* (1988) discussed sprinkler system with low uniformity of water distribution causing poor irrigation efficiency and crop production. The effect of sprinkler head arrangements on uniformity of irrigation was therefore studied. The study revealed that for symmetrical water distribution patterns, a triangular arrangement of sprinkler heads does not improve uniformity as much as the rectangular arrangement.

A measurable index of degree of uniformity obtained for any size sprinkler operating under given conditions has been adopted and is known as the uniformity coefficient, Cu (Michael, 1978). It is expressed by the equation developed by Christiansen (1942).

2.6.3.1 Pressure effects

Sprinklers are available for a very large range of pressure ratings. The trend is towards medium sprinkling. High pressure sprinklers provide extensive coverage (Sivanappan, 1987). Uniformity of application of the sprinkler diameter depends upon the matching operating pressure, wind effects and sprinkler spacing. If the pressure is too low, the water stream is not adequately broken up and a doughnut - shaped application pattern results. If the pressure is too high, the stream is broken up into extensively small droplets and does not carry water to the extent of the design wetted diameter (Richard H. Cuenla, 1989).

Bender *et al.* (1985) conducted tests on field evaluation of 40kpa and 100kpa spray and 170kpa and 345kpa impact sprinklers. Application rate and surface runoff were inversely related to sprinkler operational pressure and wetted diameter.

Hills *et al.* (1986) reported the results of an experiment using oscillating pressure on two types of spinner emitters and two types of spray emitters. The results of the study showed that pressure oscillation on level terrain did not improve the distribution uniformity.

Selvan *et al.* (1990) conducted study to evaluate the performance of different types of sprinkler heads under different operating pressures. A sprinkler head 1/4'' * 3/16'' size was tested at pressures of 3.0kg/cm^2, 2.8kg/cm^2, 2.6kg/cm^2, 2.4kg/cm^2 and 2.2kg/cm^2 and another garden nozzle was tested at 1.4kg/cm^2, 1.2kg/cm^2, 1.0kg/cm^2 and 0.8kg/cm^2. From the study it was found that the coefficient of uniformity increases as the operating pressure decreases. For the sprinkler 1/4'' *3/16'' nozzle size the values of uniformity coefficients were 46.78%, 50.24%, 60.60%, 62.90% and 68.03% at operating pressures 3.0kg/cm^2, 2.8kg/cm^2, 2.6kg/cm^2, 2.4kg/cm^2

and 2.2kg/cm^2 respectively. The radius of throw varies from 16.05m to 15.50m as the pressure varies from 3.0kg/cm^2 to 2.2kg/cm^2. It was also found that the discharge and the losses during sprinkling increases as the pressure increases and vice versa. The index for jet break up decreases as the pressure decreases.

Bindu *et al.* developed and evaluated a pulsating mi ro sprinkler irrigation system. They reported the wetted diameter and dicharge of all emitters increased with increase in pressure. The discharge varied from 22.61lit./hr to 84.58lit./hr for spinner emitters and 23.37lit./hr to 82.01 lit./hr for spray emitters at different pressures.

2.6.3.2 Effect of wind

Wind is a factor on which we have no control. Hours of high wind velocities (16 kmph) should be avoided while using a sprinkler. Sprinkler spacing is adjusted to suit wind conditions. It is generally observed that wind velocity is less at nights.

Han *et al.* (1994) developed a mathematical model to represent non radially symmetric sprinkler distribution pattern in wind conditions. For a given sprinkler/nozzle combination and operating condition, a 3-D water distribution can be generated by the model. Catch can data were used to obtain the model coefficients for impact type sprinklers operating over a 110kpa to 310kpa pressure range at wind speed upto 7m/s. Several possible sources of modelling errors were identified and the methods to improve the model were discussed. The proposed model can be used as a first approximation of sprinkler distribution pattern in wind conditions.

Bernuth (1988) studied the effect of changing the trajectory angle of a medium sized irrigation sprinkler operating in wind conditions, using a computer simulation model. The model which has been verified both in still air and under wind conditions shows that the trajectory angle that maximizes the distance of throw is a function of wind velocity. The advantage gained from trajectory angles greater than 25 in still air is quickly overcome by the disadvantageous in range reduction and drift in relatively light winds. When choosing the appropriate trajectory angle, consideration should be given to the dropsize distribution and wind velocity; because both wind drift and range depend upon dropsize and trajectory angle.

Heman *et al.* (1983) conducted a number of sprinkler studies which relates wind to sprinkler uniformity. The direction and speed of wind, height of risers, nozzle size and pressure turbulance in the stream of water entering and leaving the nozzle and jet angle were found to have an effect on sprinkler pattern distribution.

Cuecca (1989) reported that wind losses are fairly significant if sprinkler nozzle are located high above the crop canopy where they are subjected to higher wind velocities than those that occur close to canopy.

Spray from sprinklers is blown by wind and this can distort wetting patterns and upset irrigation uniformity. To reduce the effect of wind the sprinklers can be brought close together. In the prevailing wind conditions the laterals are positioned at right angles to the wind direction, reducing sprinklers along the lateral (Kay Melvyn, 1984). However when sprinklers are installed at a lesser height, the wind effect is considerably reduced due to the shielding by the canopy and lesser wind velocities near the ground.

3.6.3.4 Evoporation losses during sprinkling

Dhotrey *et al.* (1985) determined evaporation losses during sprinkling under various operating and climatic conditions by catch can method. Vapour pressure deficit and wind velocity were the major factors influencing the spray loss. The linear relationship was observed between the evaporation loss and vapour pressure deficit where as the relationship between wind velocity and evaporation loss was nonlinear. The rate of evaporation loss was quite high for the wind velocity upto 8Kmph.

Christiansen (1942) observed that the evaporation losses ranged from 10 to 42 per cent. He developed an indirect method of estimating evaporation losses through the use of thermodynamic principles. Frost *et al.* (1975) developed a nomograph for estimating the losses based on temperature, wind movement, operating pressure ,nozzle diameter and breaking of spray. They reported the spray losses under extreme conditions of high temperature and low humidity as high as 35 per cent to 45 per cent.

Kraus (1961) determined the spray losses with a single lateral, the result showed that the values of spray losses estimated from the nomograph developed by Frost and Sehwalen were low. The data reported by Kraus showed losses upto 20 percent higher than the nomograph. Wiser *et al.* (1961) reported that the evaporation losses during sprinkling was approximately the same as evaporation from free water surface under similar mateorological conditions. According to Kraus (1966) the total application losses ranged from 3.4 per cent to 17 per cent and on the average 36 percent of the total loss was due to drift.

Evaporation losses are made up of sprinkler spray evaporation and surface evaporation from the free water on the plant and soil. These losses are low during sprinkling. A typical farm system operating at 2kg/cm^2 to 3.5kg/cm^2 has negligible losses under cool weather and low wind conditions. Even at high wind velocities of 25Kmph, the losses for 24 hours sprinkling period on a growing crop do not exceed 8 per cent. On bare ground the losses may be double the amount. Therefore 24 hours of operation in a day was found to be feasible for irrigating the crop without much loss (Sivanappan, 1987).

Hussain (1992) carried out a study of spray losses from three low pressure, centre pivot sprinkler irrigation systems under field operating conditions. The evaporation losses during sprinkling were determined at three different spray nozzle heights from ground surface. The average values were 15.63%, 21.19% and 35.77% for heights of 1.25m, 1.75m and 2.5m respectively.

2.6.4 Splash detachment under sprinkler irrigation

Soil erosion has been characterized as a process of detachment and transportation of soil materials by erosive agents. Generally the drop (rain) impact may serve as a mechanism for supplying detached soil materials.

Francis *et al.* (1983) studied the effect of initial water content of a loam soil on the stability of aggregates and found that soil will become more susceptable to detchment as the soil water content increases during [illegible] and sub surface. They reported erosion can occur under sprinkler irrigation if the application rate exceeds the infiltration rate and water run off. This seldom occurs when stationary sprinklers are used but is common near the outer end of low-pressure centre pivot systems, where application rate generally exceed 50mm/hr and may exceed 100mm/hr. Since only a small portion of the field receives high center -pivot application rates at one time, runoff and thus eroded sediments are seledom conveyed far from the eroding slope, and off site impact is usually small. The measurements showed that soil loss under centre pivots can be significant especially for row crops and the amount of erosion increases with increasing slope.

Trout (1993) reported the erosion and sedimentation process on irrigated fields. Soil erosion is sometimes excessive during furrow irrigation and under center pivot sprinkler systems. Soil erosion occurs when fluid in motion detaches and transports particles. Sedimentation occurs when the fluid transport capacity decreases less than the sediment load. Hydraulic forces of moving water and soil factors such as aggregate stability and particle size determine erosion and sedimentation. With sprinkler irrigation, water drop energy detaches particles, some of which may be transported down the slope by shallow inter rill flow, if the water application rate exceeds the soil infiltration rate.

Many research works have shown that splash detatchment is the function of kinetic energy of droplet in the form

Splash detatchment = a KE^b

where KE = Kinetic energy

`b' ranges in value from 0.8 for sandy soils to 1.8 for clays (Bubenzer and Jones, 1971) with `a' value of 1.0 being reasonably representative (Quansh,1981).

2.6.5 Surface slope effects

Soares *et al.* (1991)conducted studies to determine surface slope effects on sprinkler uniformity. They reported that the slope of the soil surface has a significant effect on water distribution from sprinklers. Field tests were conducted to quantify the effects. A ballastic trajectory model was developed to simulate precipitation data for a sprinkler working on different ground slopes and different sprinkler riser angles.The model uses precipitation data from a single sprinkler working on a zero slope plane under no wind condition. The model is verified against measured data for a sprinkler operating on a slope. A study is made on the influence of sprinkler riser angle, nozzle angle and soil surface slope on the uniformity of water distribution. The results show that the sprinkler riser should be kept perpendicular to the soil surface to maximise the uniformity of water application and to minimise the erosion risk. Higher nozzle angles are preferable to lower nozzle angles when working on steep slopes, but higher nozzle angles increase sensitivity to wind. With higher nozzle angles slope is less critical.

Wu *et al.* (1983) reported sprinkler irrigation design for uniformity on slopes. They concluded that the energy gradient line of a sprinkler irrigation lateral (or sub main) can be expressed by a dimensionless energy gradient curve. The pressure variation along a lateral (or submain) can be determined by combining the friction drop and energy gain (or loss) by slopes. A design chart has been developed for uniform down slope situations. A simple program was also developed for non uniform slope situation calculation. The main objective of the study was to include the slope effects in the design of sprinkler systems.

Woodward (1957) stated that the pressure variation along a lateral line be held to 20 per cent. So the discharge variation from all the sprinklers along the lateral would be maintained to be equal or less than 10 per cent. The pressure variation along a lateral can be expressed by

$$Hvar = \frac{Hmax - Hmin}{Hmax} * 100$$

where Hvar = pressure variation in percent

Hmax = maximum pressure head (m)

Hmin = minimum pressure head (m)

2.6.5.1 Effect of Sprinkler operating angle

Grant *et al.* (1984) conducted studies on constant and variable operating angle sprinklers for traveller irrigations. Digital simulations were used to determine the amount of water applied by a traveller irrigation system. The simulations include an initial stationary set (travel delay) to provide additional water behind the start position of the traveller. A comparison of the two series simulations was made to determine the potential of utilizing an alternate sprinkler operating angle during the initial delay period. This was accomplished by conducting a series of simulations with a constant sprinkler operating angle and a second series with different sprinkler angles for the delay and travel periods. Required delay time, uniformity of application and the volume of water applied beyond the effective field boundary were used as the performance criteria used in the comparison.

Chen *et al.* (1984) reported economic sprinkler selection, spacing and orientation. Simulation and graphical methods were developed. Cost, application rate, uniformity and full aerial coverage were functions of spacing along the lateral and between the laterals. A graphical representation of uniformity, coverage, and application rate was simulated as a function of spacing. An economic method to select, space and orient sprinklers was also introduced.

Materials and Methods

MATERIALS AND METHODS

Most of the works for the evaluation of sprinkler uniformity have been conducted on plane lands, and only a few works have been reported on sloping lands. A field study was conducted to find out the effect of land slope on uniformity of water distribution of sprinklers at Kelappaji College of Agricultural Engineering and Technology, Tavanur. Materials used for the study and the methodology for achieving the objectives are discussed in this chapter.

3.1 Location

The experiment was conducted in the instructional farm, Kelappaji College of Agricultural Engineering and Technology, Tavanur in Malappuram District. The place is situated at 10°53'30'' North latitude and 76° East longitude. The total area of KCAET comes to about 40.99ha, out of which, the total cropped area comprises 29.65ha.

3.2 Experimental set up

The experiment was conducted on an artificially made platform (Fig.1). The upward slope of the platform was oriented eastward as far as the geography of the study site was concerned. The platform was made of arecanut reapers of size 12m * 12m. Each reaper was laid 1m apart making a total of

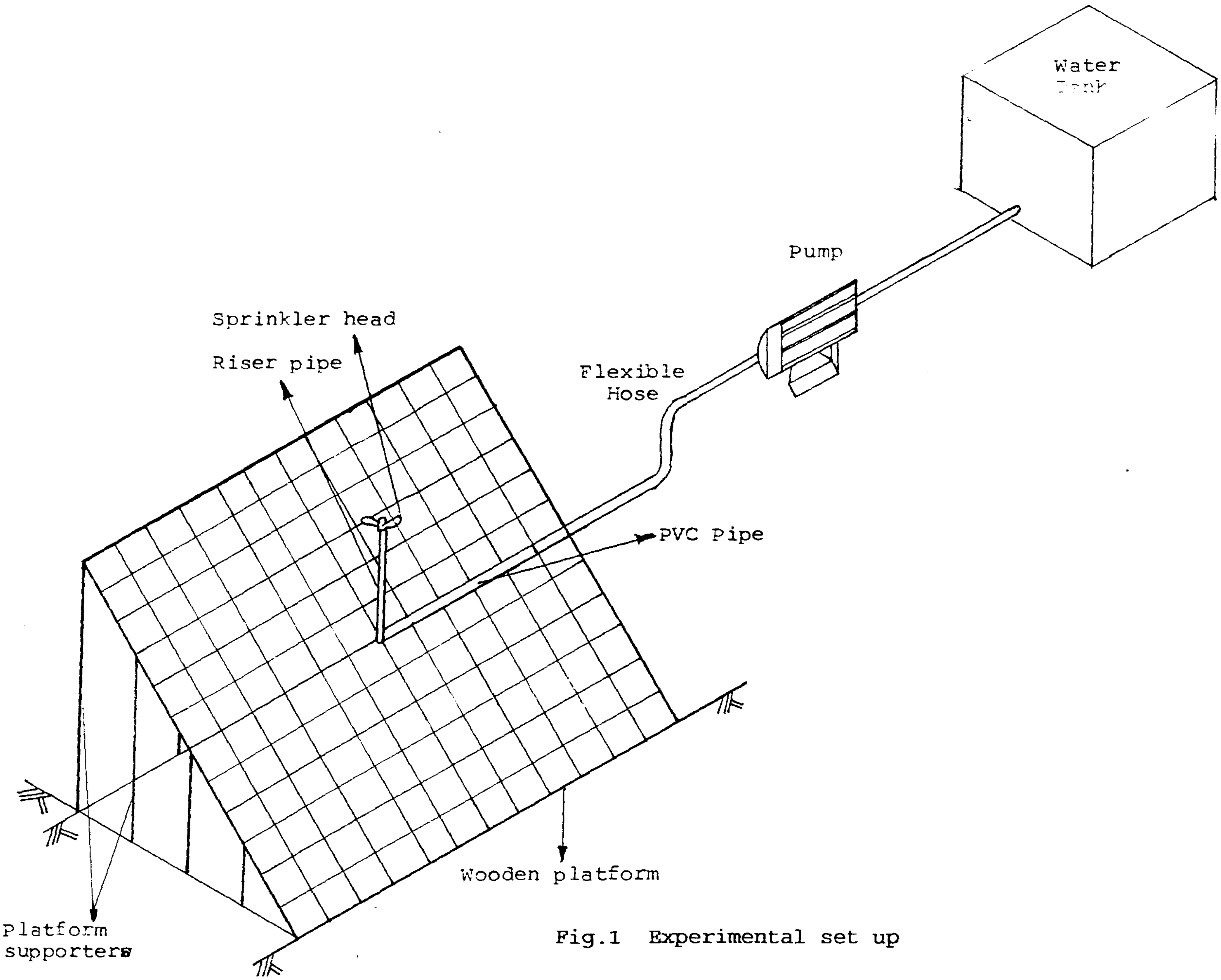


Fig.1 Experimental set up

Plate 1 Wooden platform (view from down slope)

Plate 2 Wooden platform (side view)

144 grids. One of the sides of the platform was kept on plane ground and the opposite side was held up with the help of bamboo poles. The heights of the bamboo poles were adjusted to achieve the desired slope. Sufficient supports were given with the help of bamboo poles at 3m intervals, for proper stability of the platform.

In this study single nozzle sprinkler head of 4.4mm nozzle size was used. The nozzle angle was 28°. It was mounted on a GI riser pipe of 12.5mm diameter at a height of 1.5m. A GI socket with same diameter as the riser pipe was used to connect the sprinkler head. The other end of the riser pipe was connected to a PVC pipe of 5m length and 50mm diameter by means of a GI reducer tee of size 50mm * 12.5mm. The PVC pipe was attatched to a 50mm flexible hose having a length of 10m. The flexible hose was connected to the pump. An FTA and MTA of 50mm were used for proper connection. In the discharge line, at the open end of the PVC pipe a 50mm size block nut was used. The PVC pipe was placed in such a way that it can be tilted for varying the riser angles. A pressure gauge was attatched to the riser pipe to measure the operating pressure of the sprinkler. A centrifugal pump operated by electric current was used to pump water. Catch cans were provided at every junction on the platform for collecting water (Fig.2).

The tests were conducted for three different slopes and also for a non slope condition. The three slops were 12.5 %,

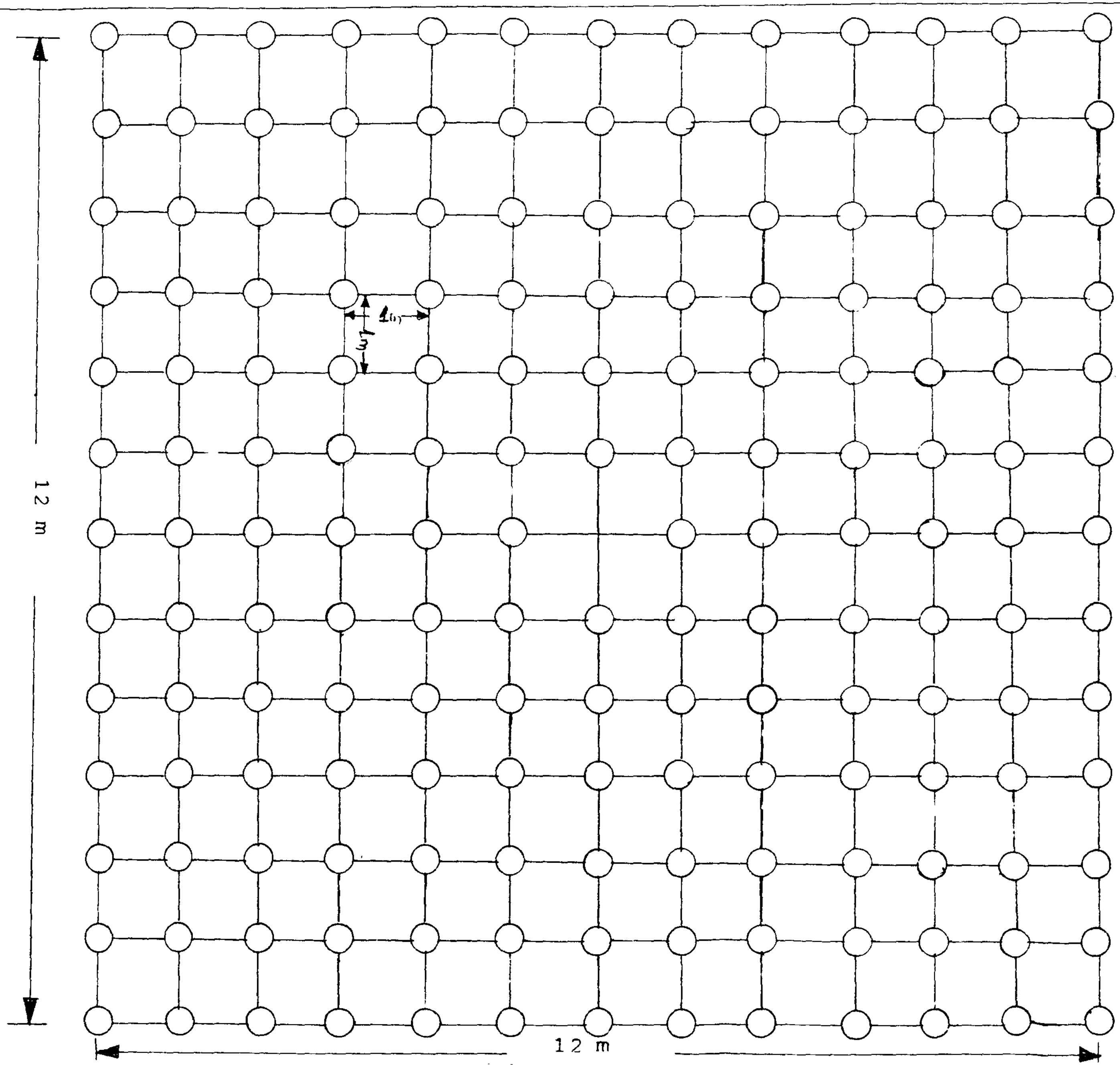


Fig.2 Arrangement of catch cans on wooden platform

10.0 % and 7.5 %. The riser pipe was kept in three positions namely vertical, midway between vertical and perpendicular and perpendicular to the land (Fig.3). In vertical position the riser pipe will be normal to the plane land and in perpendicular position it will be normal to the sloping land. In midway position the riser pipe will be in the centre between vertical and perpendicular positions. The slope was varied by adjusting the height of the supporting bamboo poles.

During the operation of sprinkler, the operating pressure was kept constant by supplying constant amount of water. The discharge rate of the sprinkler was also noted. The performance of the sprinkler was noted in different wind conditions.

3.2.1 Water source

A circular tank of 0.6m diameter and 1.3m height was used as the source of water. Water was filled into the tank with the help of a flexible hose of 1/2'' diameter from the main pipe line.

3.2.2 Pumping unit

A centrifugal pump operated by 1 HP 230 V electric motor was used to develop sufficient pressure. The suction and delivery pipes of 50mm diameter were used.

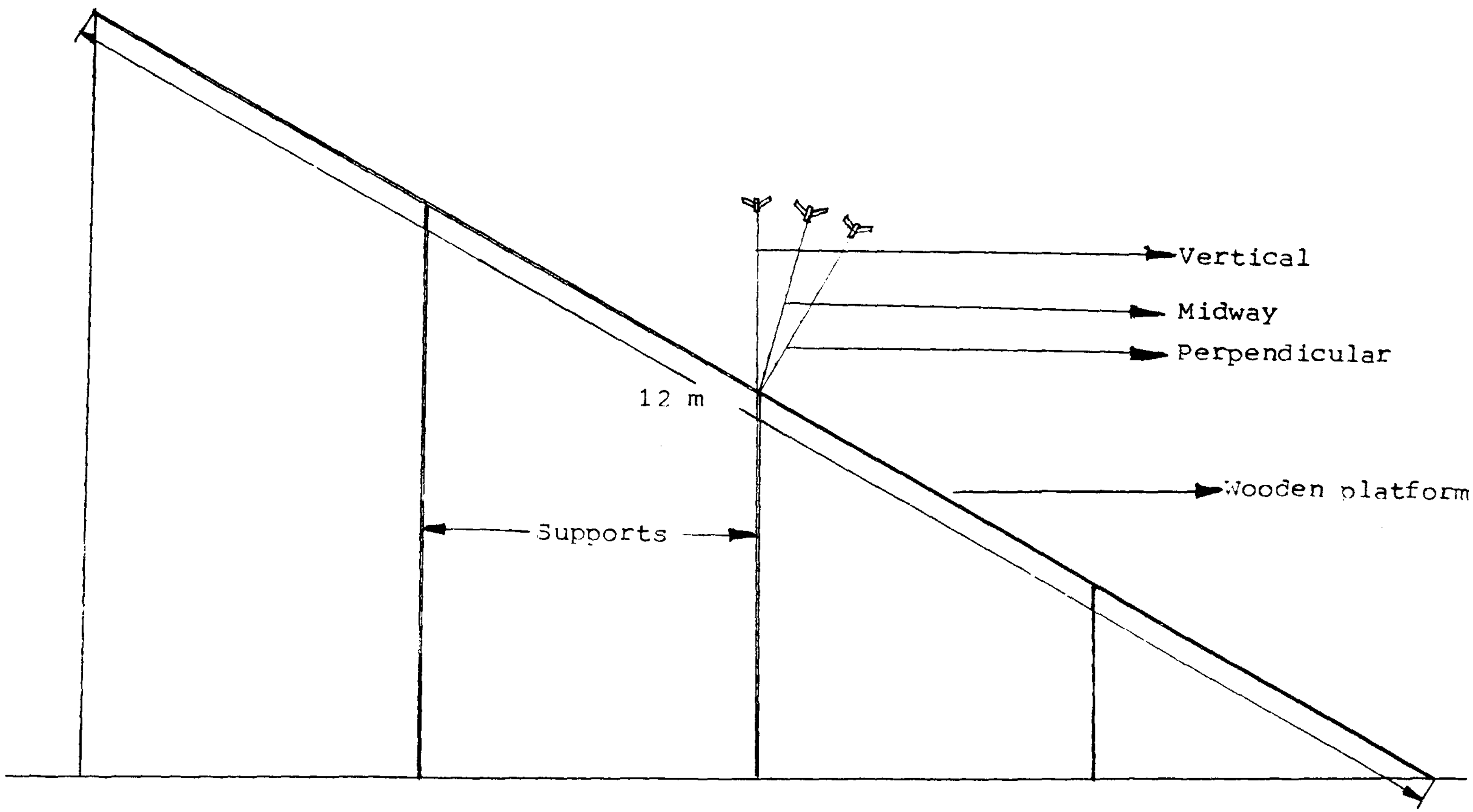


Fig.3 Different riser positions (Side view)

Plate 3 PVC pipe attached to the riser pipe

3.2.3 Sprinkler head

A single nozzle sprinkler head supplied by the Voltas Limited was used in this study. The spray diameter was 12.0mm. The sprinkler was operated by forcing water under pressure through the nozzle and into the air. The jet broke up into small drops as it travelled through the air and fell to the ground like rainfall. The rotation of the sprinkler was in a horizontal plane producing a circular wetting pattern. The sprinkler rotation is caused by the water jet and the spring loaded swing arm. When the sprinkler operate, the swing arm interrupts the water jet and is forced sideways by the flow. Once clear of the jet,the arm returns, owing to the spring tension and interrupts the jet again. On returning however, the arm strikes one side of the sprinkler, causing it to turn slightly. This action is repeated in a steady beating motion causing the sprinkler to rotate slowly. The speed was adjusted by the swing arm spring tension.

3.3 Measurement of pressure

A Bourdon pressure gauge was used to measure the operating pressure of sprinkler. It was connected on the riser pipe near to the sprinkler head.

Plate 4 Sprinkler head

3.4 Measurement of wind

Anemometer was used for measuring wind velocity. The distance moved by the needle for a particular time interval was noted. By dividing the cumilative distance travelled with the time interval the velocity was obtained.

The anemometer was installed at a distance of 1 m from the side of the experimental field. The direction of the wind was noted with the help of a wind vane (Fig.4). In all the cases the wind was eastwardly.

3.5 Discharge measurement

Discharge from the sprinkler was measured by connecting a flexible tube of diameter 1 cm greater than the size of the nozzle and collecting the discharge in a specified container and noting the time taken to fill it.

$$\text{Discharge(lit./sec)} = \frac{\text{Volume of container (litre)}}{\text{Time taken to fill the container (sec)}}$$

3.6 Determination of distribution pattern

After operating the sprinkler for half an hour duration, the volume of water collected in each can was measured. A measuring jar of 25ml capacity was used for volume measurement. The uniformity of distribution was analysed using a computer

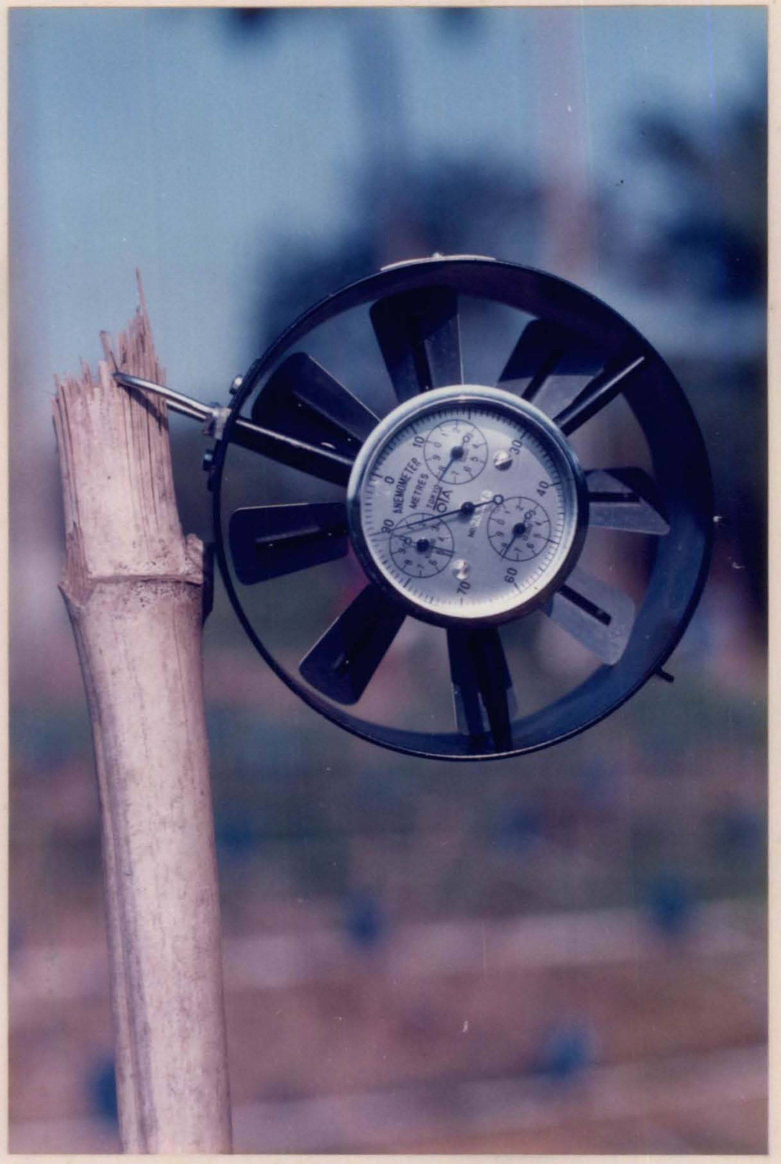


Plate 5 Anemometer

software package namely `SURFER'. The uniformity was determined for different wind conditions. The Cu values were calculated using the equation

$$Cu = 100 \left(1 - x / mn \right)$$

in which Cu = uniformity coefficient in percentage

m = average value of all observations (average application rate)

n = total number of observation points

x = numerical deviation of individual observations from the average application rate

For the no wind conditions the readings were taken in the early mornings when there was little or no wind. The other readings were taken in the evenings. The same procedure was carried out for the three prescribed slopes. For each slope the riser was kept in three positions viz, vertical, midway between vertical and perpendicular and perpendicular to the grid, with the help of PVC pipe. The uniformity of water distribution was also analysed on flat land condition. All the experiments were conducted three times for the same riser position.

3.7 Measurement of rotation rate of sprinkler head

The time taken for one rotation of the sprinkler head was noted with the help of a stop watch for different slopes and riser angles. The rotation rate was noted for different wind conditions. The time taken for rotation in upward half and downward half of the slope was noted seperately.

3.8 Measurement of erosion

A plastic sample holder of 25cm diameter and 8cm depth was taken. At the bottom of the sampler, holes were provided to fecilitate drainage. The sampler was filled with the soil representing the profile of the field and was levelled.

The sample holder was kept on the platform, midway between the riser pipe and the upper half. A vessel was also provided under the sample holder for collecting the detatched soil particles. The sprinkler was operated for half an hour. Then the soil particles detatched along with water was collected from the vessel in small containers. The water was allowed to evaporate and the weight of oven dried splashed soil was taken. The same procedure was carried out for different slopes and different riser angles.

Plate 6 Measurement of water collected in the catch can

Results and Discussion

RESULTS AND DISCUSSION

The various observations obtained from the experiments conducted are analysed and the results are presented in this chapter.

4.1 Water distribution pattern

The water distribution pattern of the sprinkler head for different landslopes and riser angles were determined. Isohytes were drawn with the help of a computer soft ware available at K C A E T, Tavanur for the above distributions and are shown from Fig. 5 to Fig 22.

Uniformity coefficients were calculated for all the conditions tested, and are shown in Table 1. Different combinations of overlappings were tried to determine a satisfactory uniformity coefficient for each of the condition, and are shown in Table 1.

Figure 5 to Fig. 10 show the water distribution pattern for 12.5 per cent land slope. It was found that for no wind conditions the uniformity of water distribution was increasing as the riser position changes from vertical to perpendicular. In order to get a satisfactory uniformity the overlap recommended is between 45% and 50% for vertical position and between 40% and 45% for mid way position. However for perpendicular position the moisture distribution was almost uniform. The recommended overlap is between 36% and 40%. The spacing of the sprinklers can be set at appropriate intervals in order to get the required percentage of overlap for different riser positions. But for wind conditions the water distribution was not uniform in any case. It could be seen that in such conditions

Table 1. uniformity Coefficients and recommended overlapping for different conditions.

Conditions	Cu values (%)	Cu values on overlapping (%)							
		30%	35%	40%	45%	50%	55%	60%	65%
I. 12.5% slope									
vertical	5.7	64.2	68.5	76.5	81.2	86.5			
Midway	13.6	72.3	77.5	80.5	86.8				
Perpendicular	24.7	78.8	81.7	83.5					
II. 10% slope									
Vertical	8.3	74.5	77.3	80.7	83.1	84.3			
Midway	16.2	76.1	78.4	82.5	85.3				
Perpendicular	25.3	78.6	82.3	84.2					
III. 7.5% slope									
Vertical	12.8	76.2	78.5	80.7					
Midway	18.3	78.8	81.5	84.1					
Perpendicular	25.4	83.2	87.6						
IV. Wind conditions	2.5	50.6	55.2	59.4	67.5	70.2	76.5	80.2	84.6

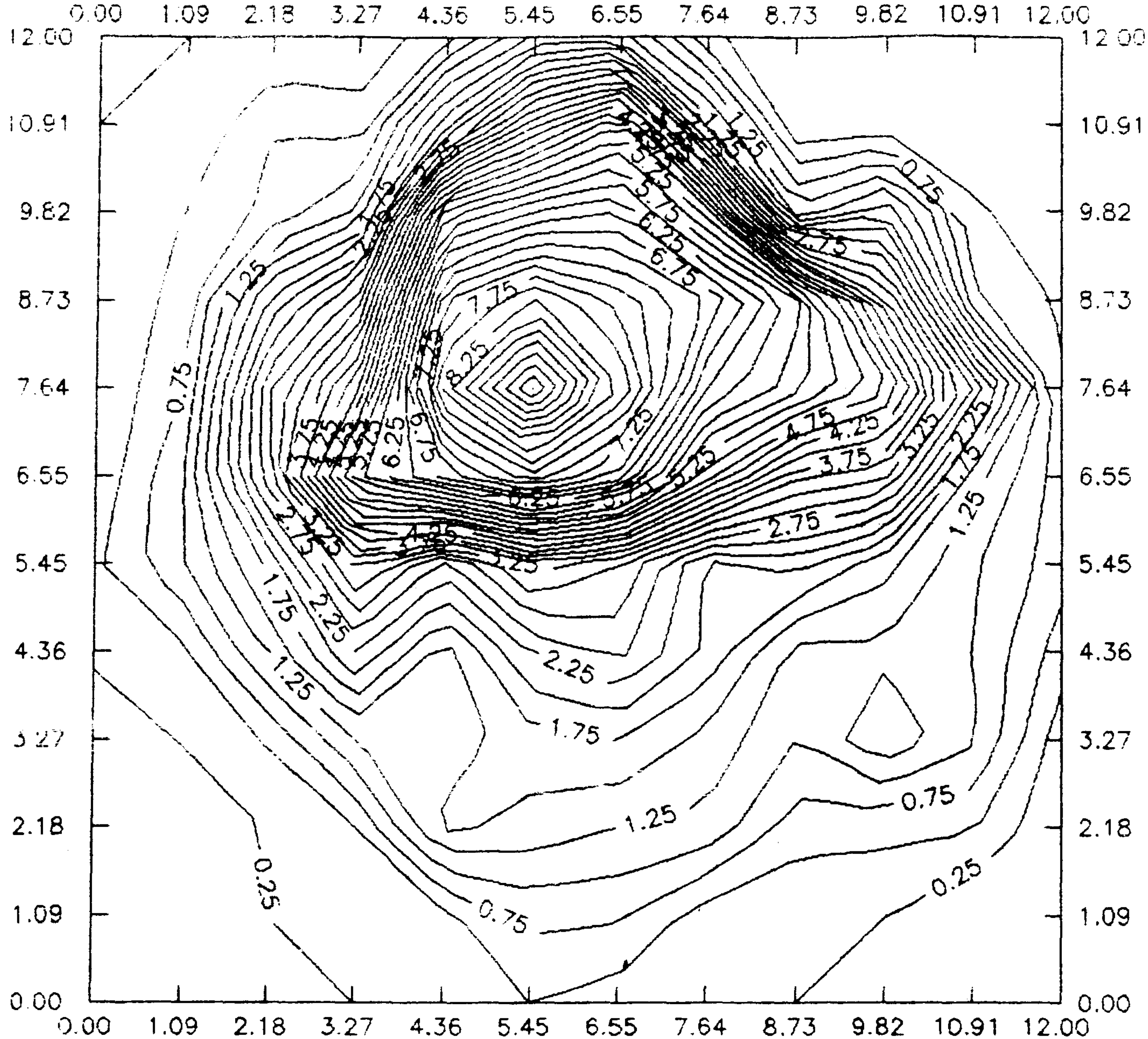


Fig. 15 Water distribution pattern at 12.5% slope, Riser position: Vertical (No wind condition)

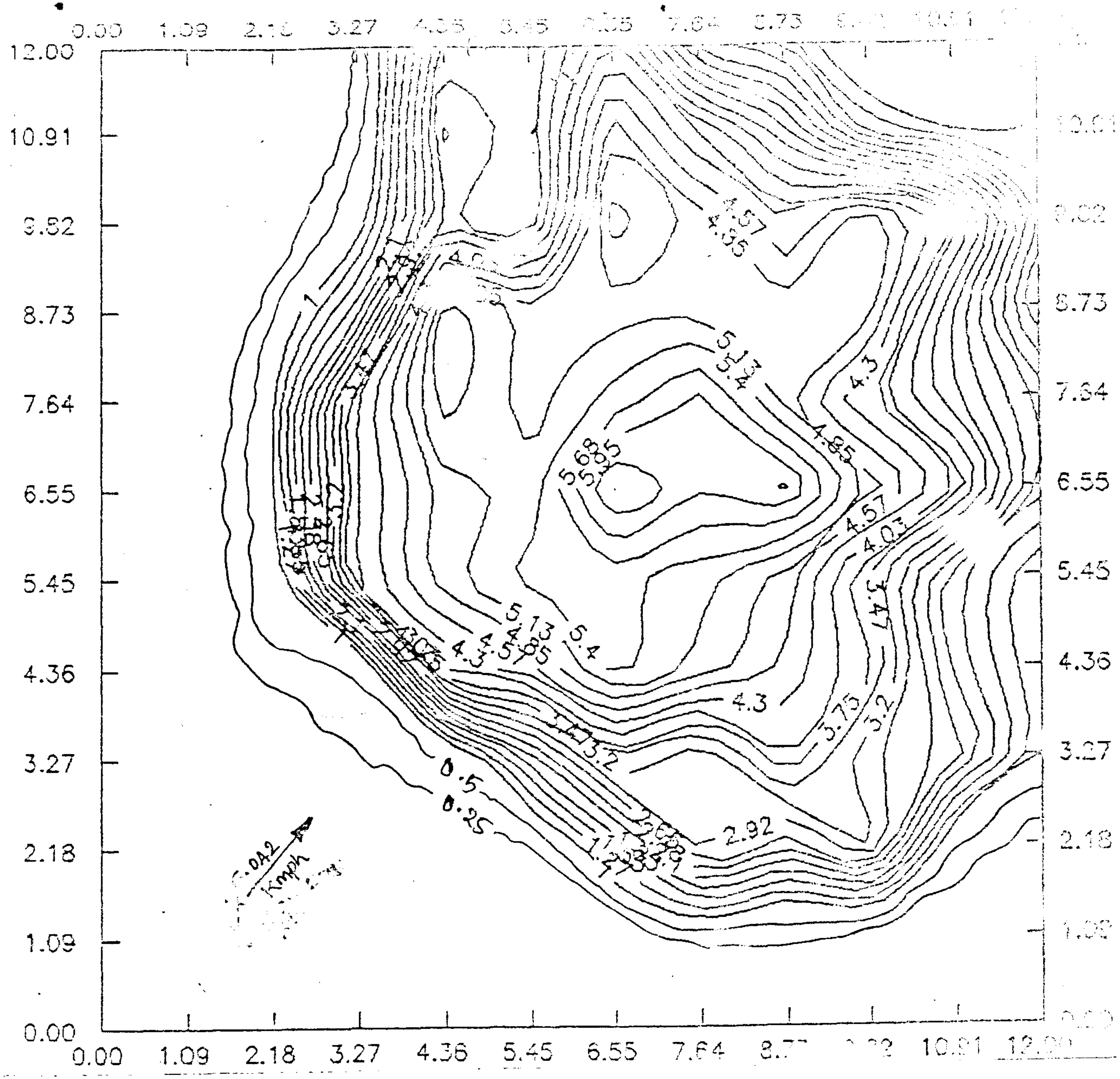


Fig.6 Water distribution pattern at 1?.5? slope, ... position: vertical (Wind condition

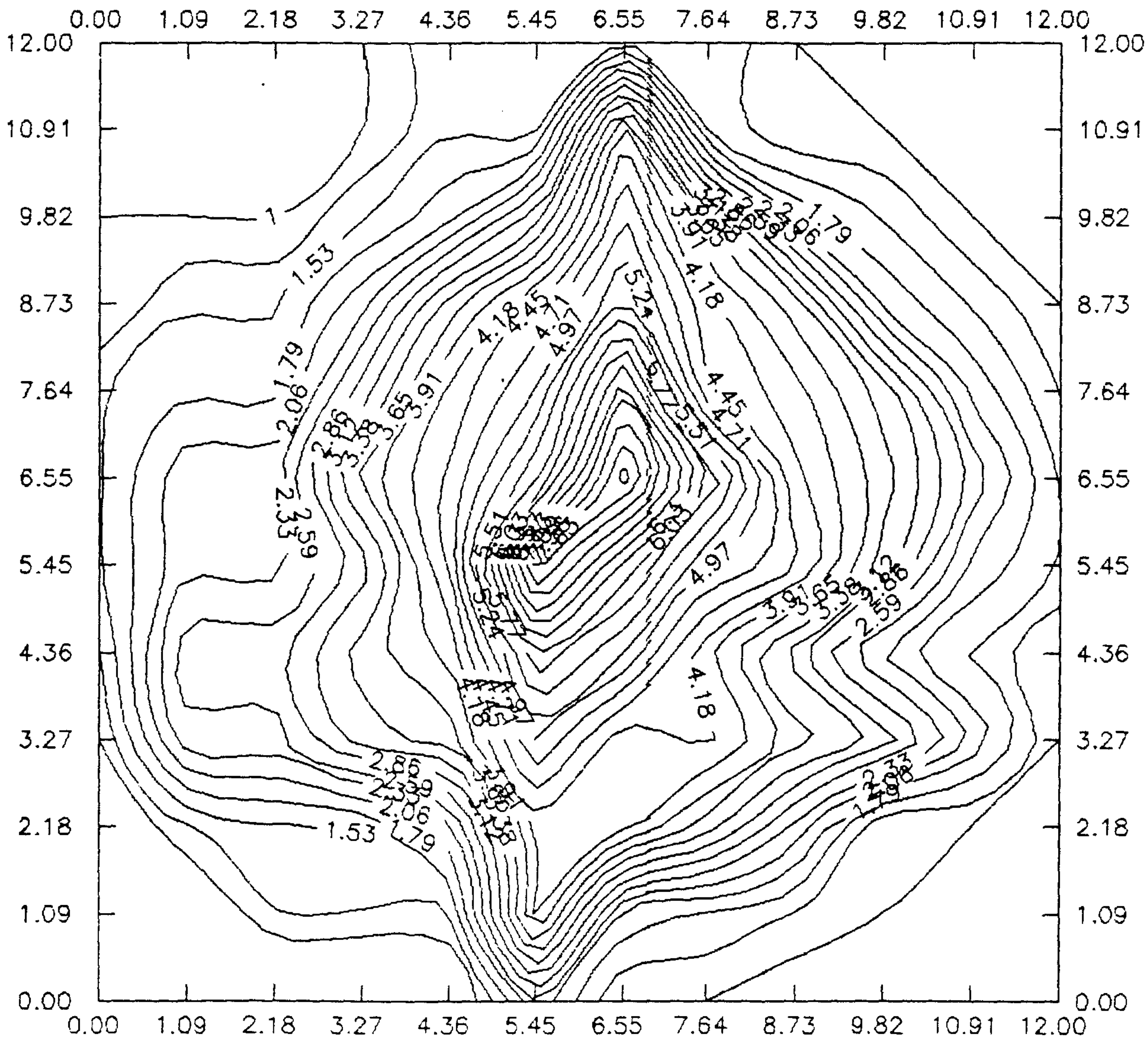


Fig.7 Water distribution pattern at 12.5% slope, Riser position: Midway (No wind condition)

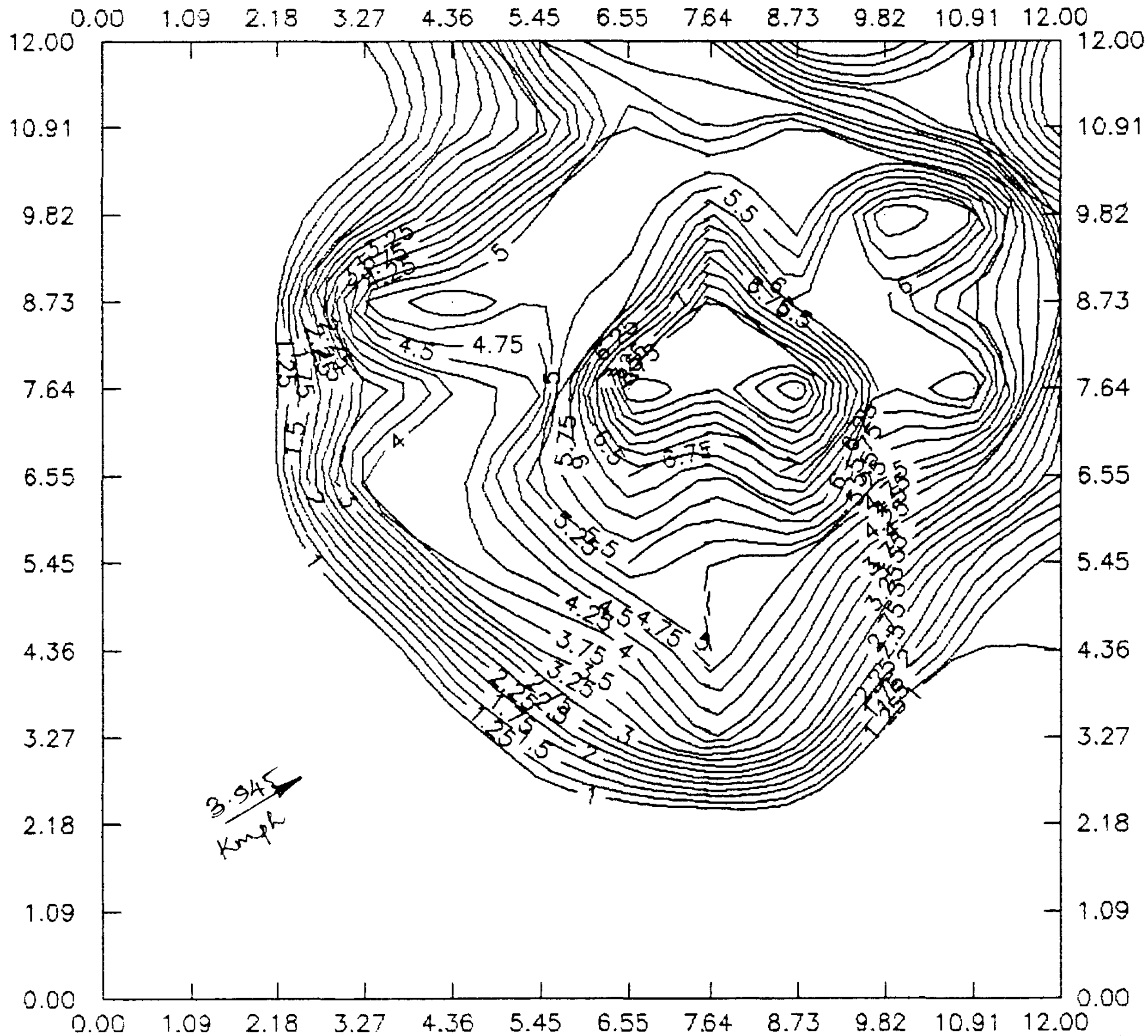


Fig.8 Water distribution pattern at 12.5% slope, Riser position: Midway (Wind condition)

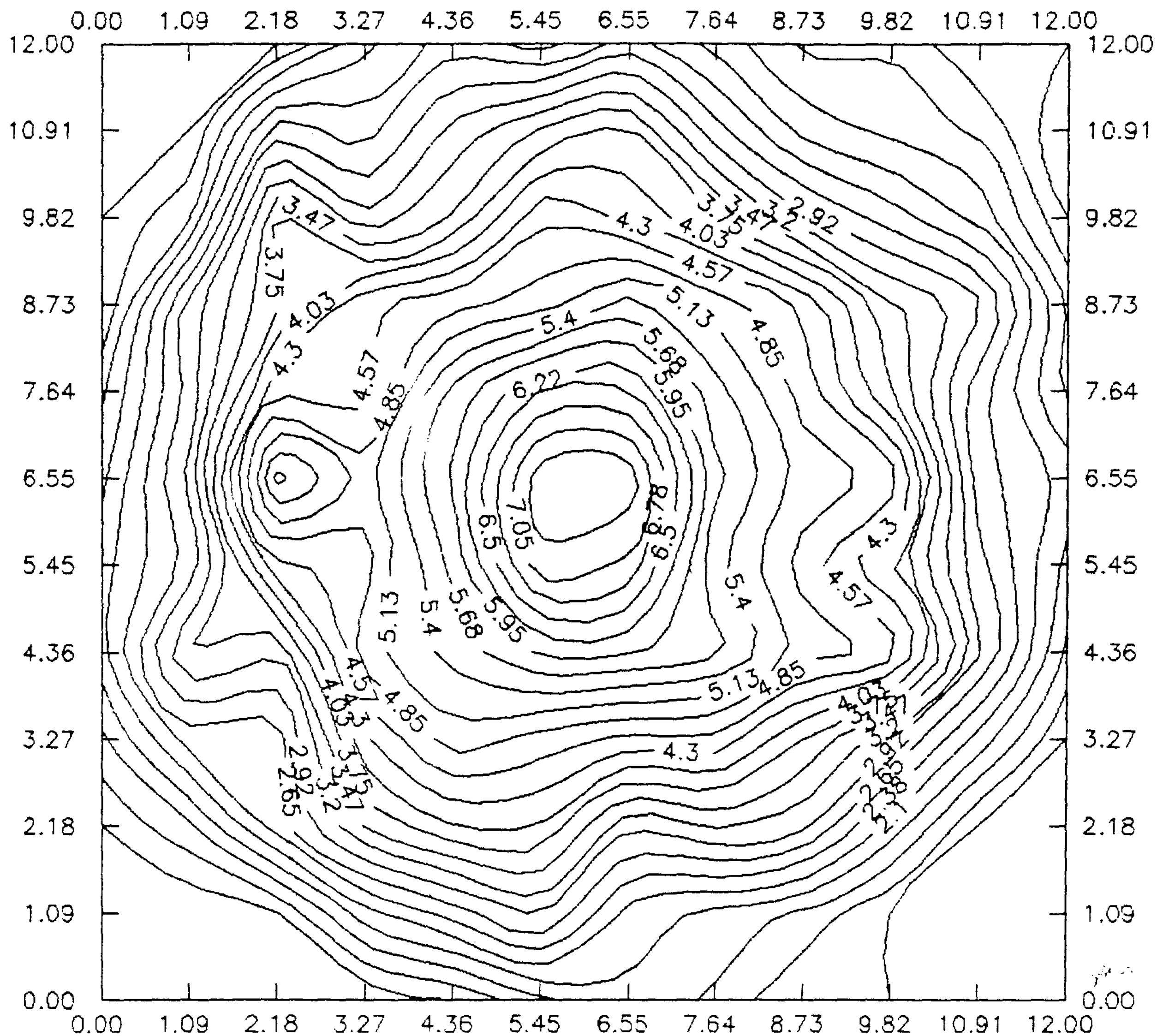
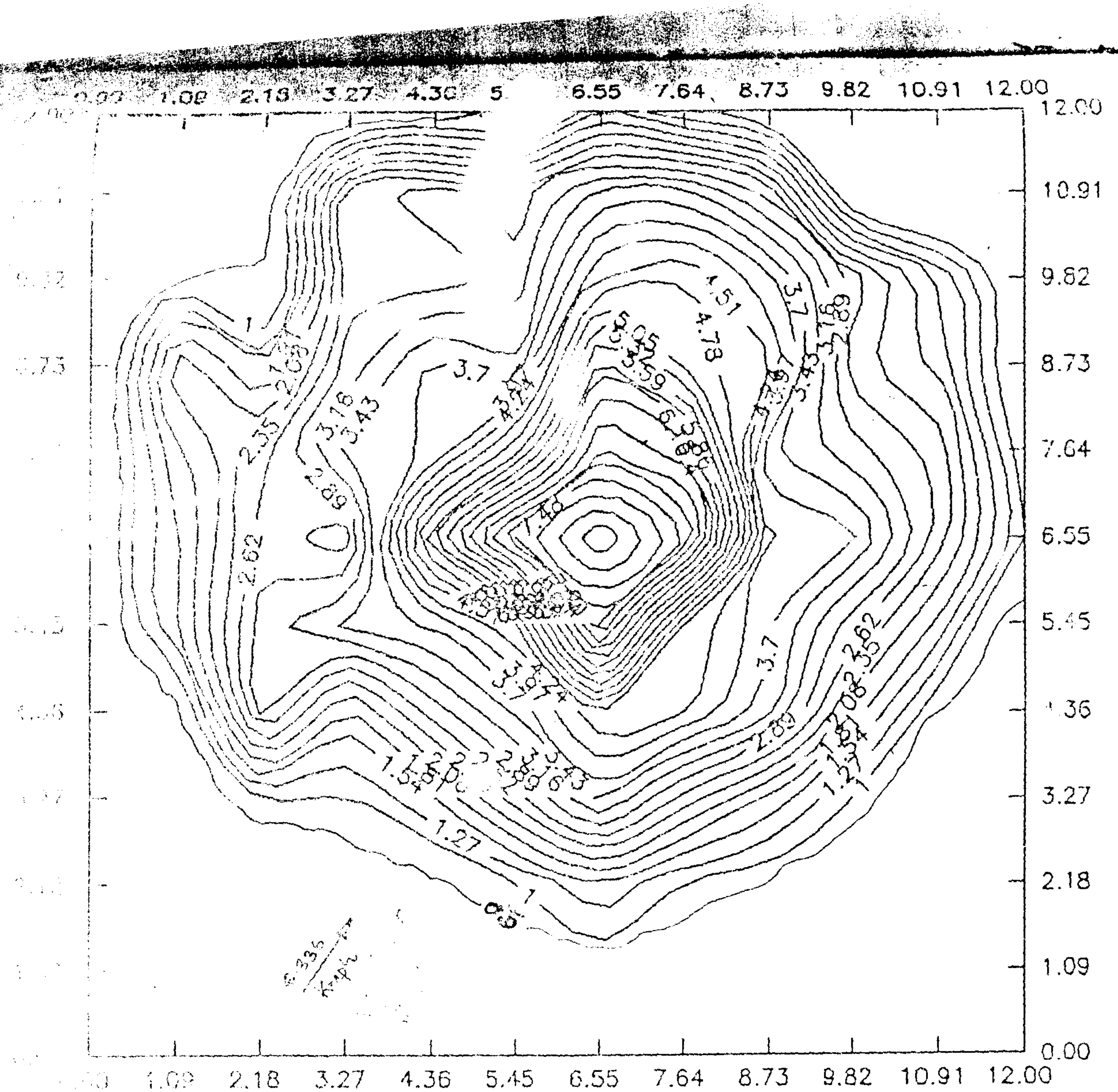


Fig.9 Water distribution pattern at 12.5% slope, Riser position: Perpendicular (No wind condition)



Water distribution pattern at 12.5% slope, Riser position: Perpendicular (Wind condition) the sprinklers must be much closer for acheiving uniform water distribution.

The water distribution pattern of the sprinkler head for 10 per cent land slope is presented from Fig.11 to Fig.16. Here also we can see that the water distribution uniformity is increasing as the riser position changes from vertical to perpendicular position. But for good uniformity the per centage of overlap recommended is between 40% and 50% for vertical position and between 40% and 45% for mid way position. Here also the wind was having an important role in water distribution. In perpendicular position the recommended overlap is between 35% and 40%.

Figure 17 to Fig.22 show the water distribution pattern for 7.5 percentage land slope. It showed that overlap between 40% to 45% will give good uniformity for vertical position and overlap between 35% and 40% is required for good uniformity in mid way position. For the perpendicular position the water distribution pattern was uniform as in the above two cases. The overlap recommended is between 30% and 35%. Similarly the wind has affected in this case also.

From the above studies it seems that for no wind condition as the land slope increases the spacing of the sprinklers is to be decreased, for uniform water distribution. But the spacing can be increased by changing the riser position from vertical to perpendicular. In all the three cases the maximum

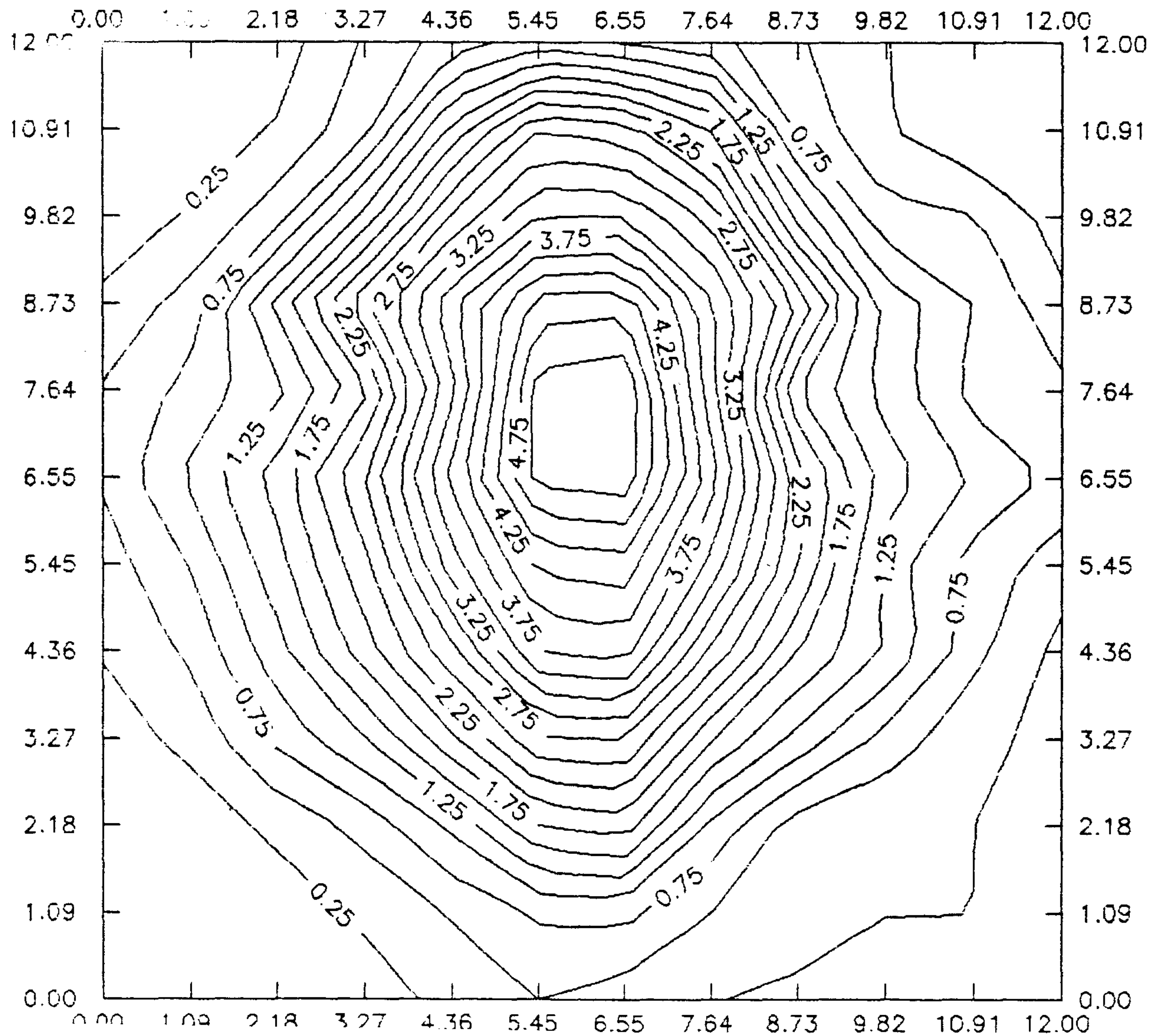


Fig.11 Water distribution pattern at 10% slope, Riser position: Vertical (No wind condition)

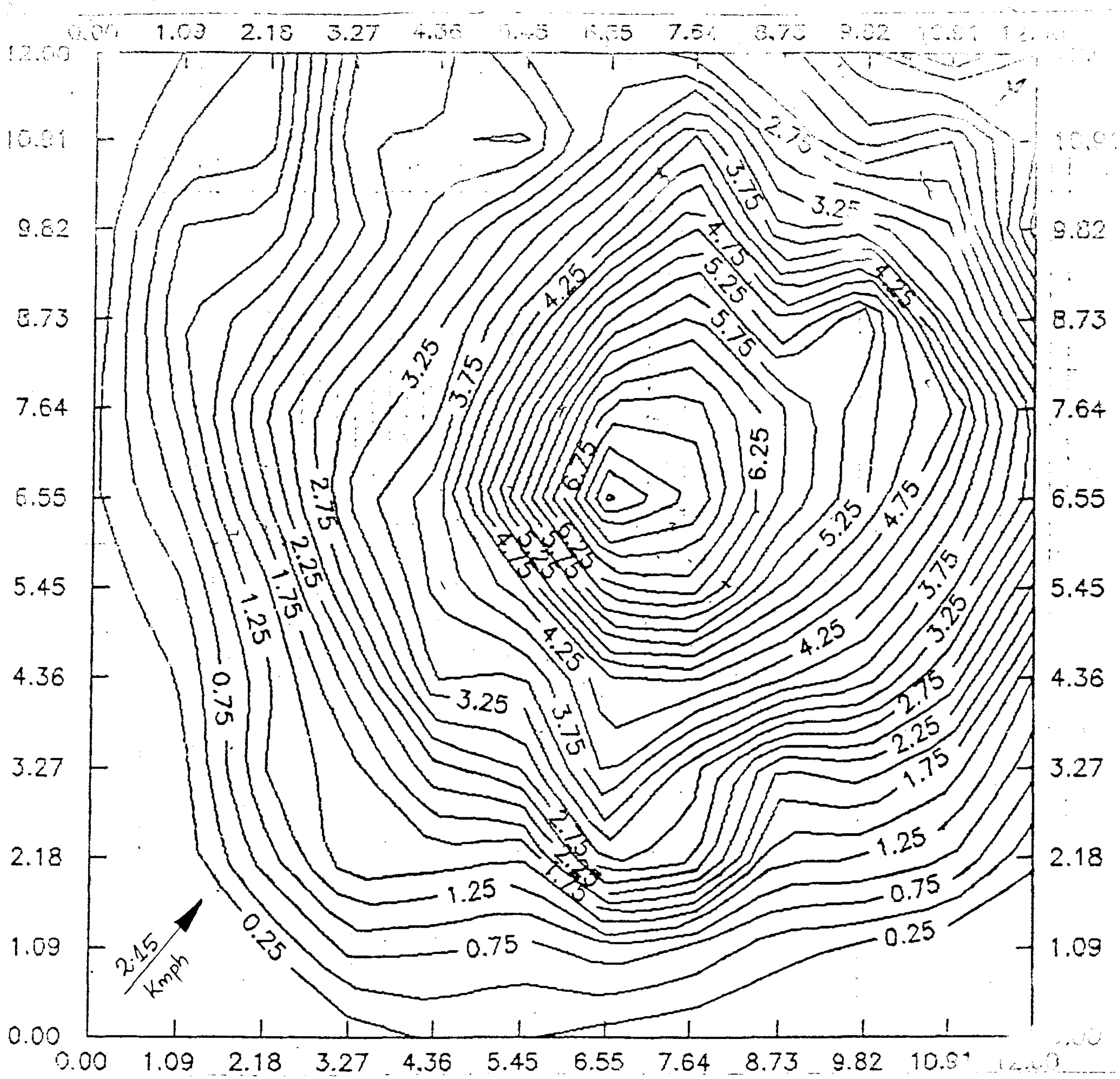


Fig.12 Water distribution pattern at 10% slope, position: Vertical (Wind condition)

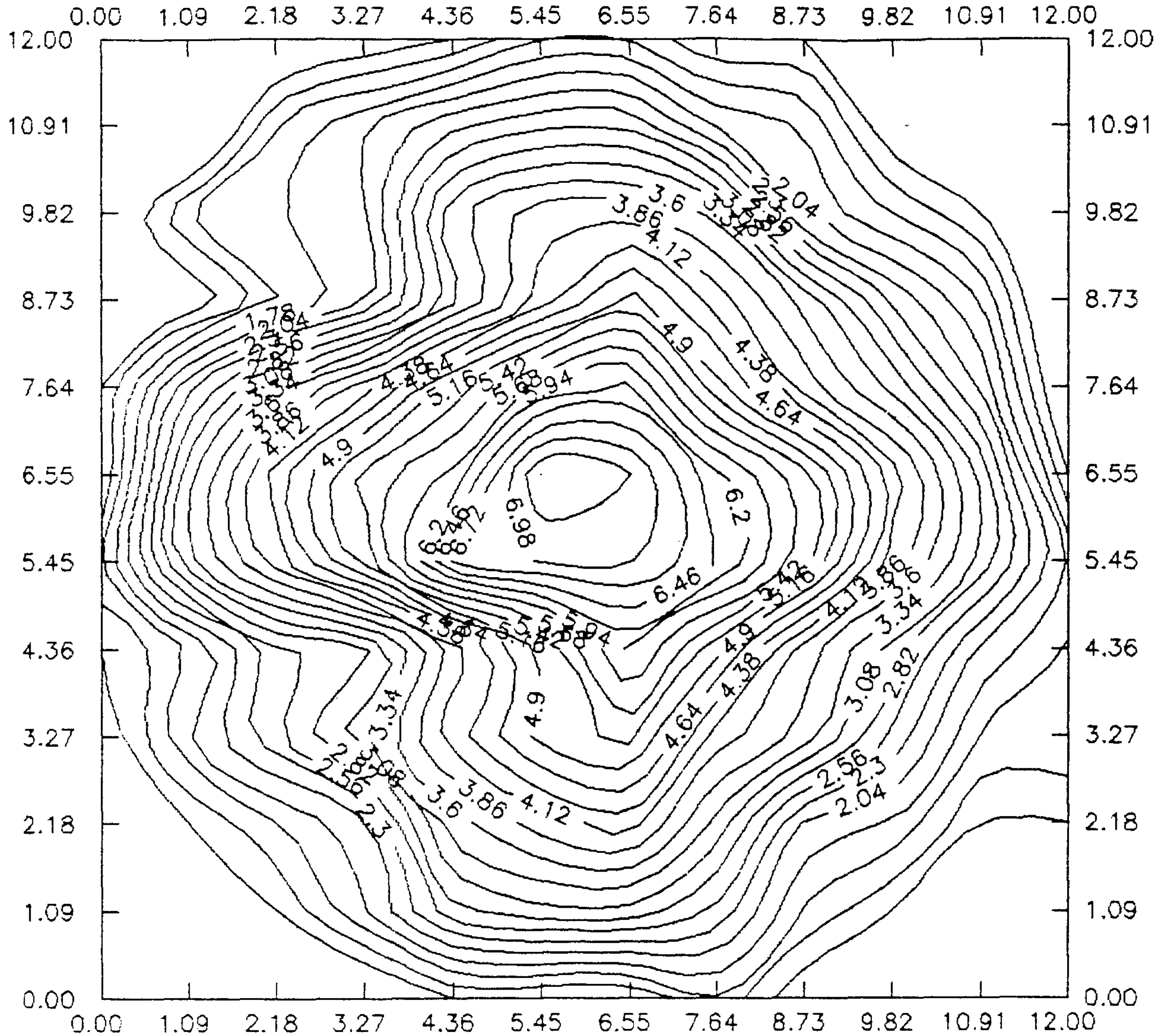


Fig.13 Water distribution pattern at 10% slope, Riser position: Midway (No wind condition)

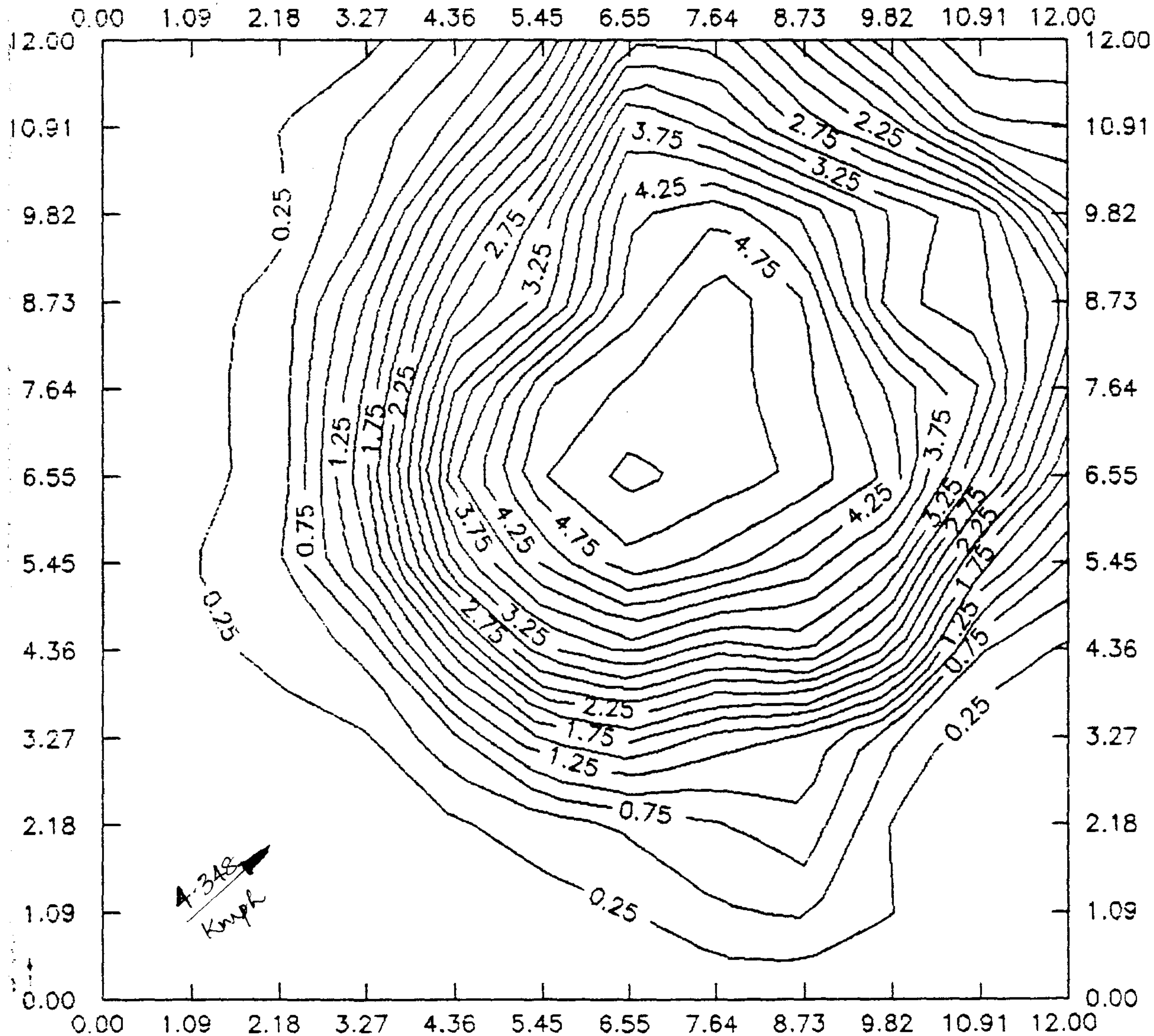


Fig.14 Water distribution pattern at 10% slope, Riser position: Midway (Wind condition)

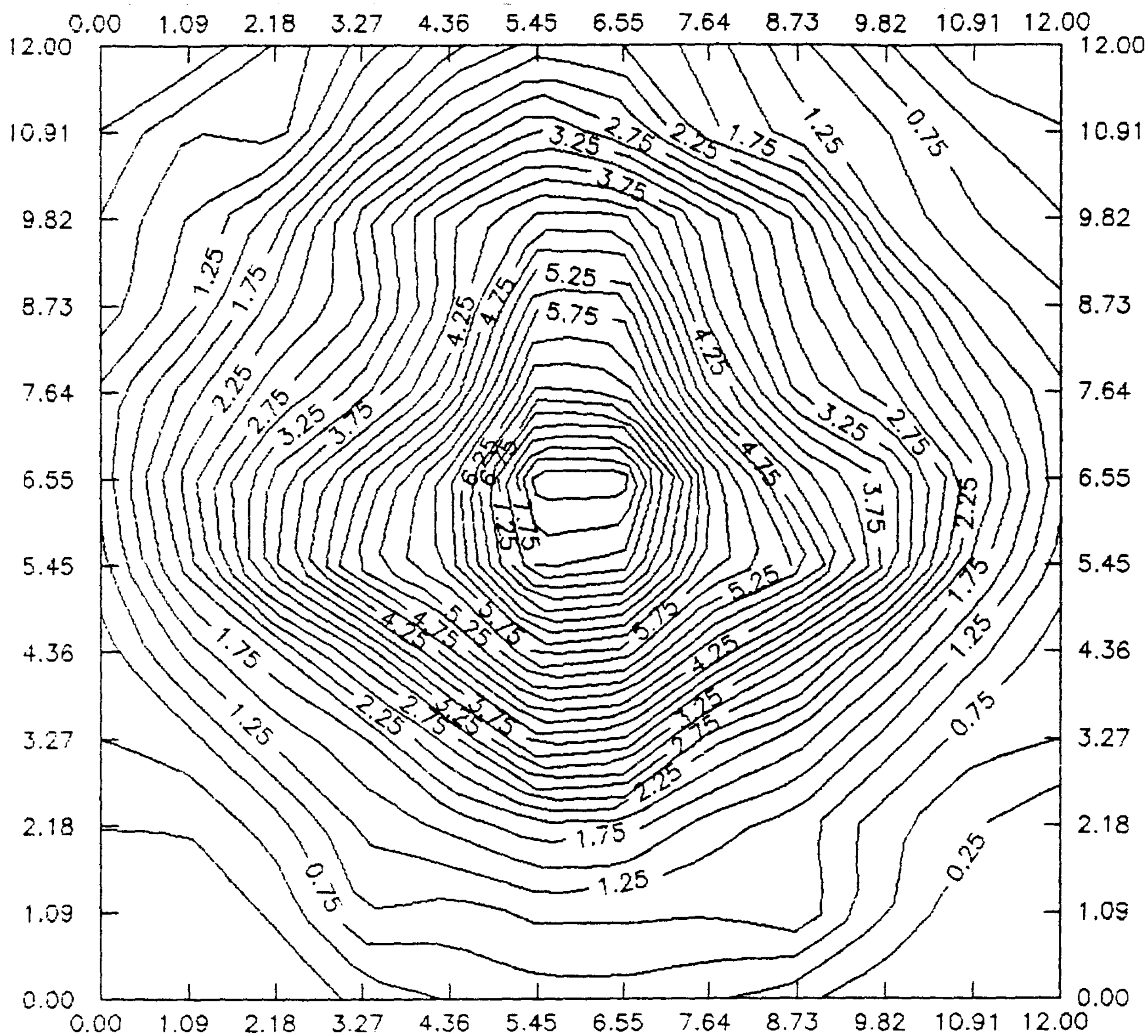


Fig.15 Water distribution pattern at 10% slope, Riser position: Perpendicular (No wind condition)

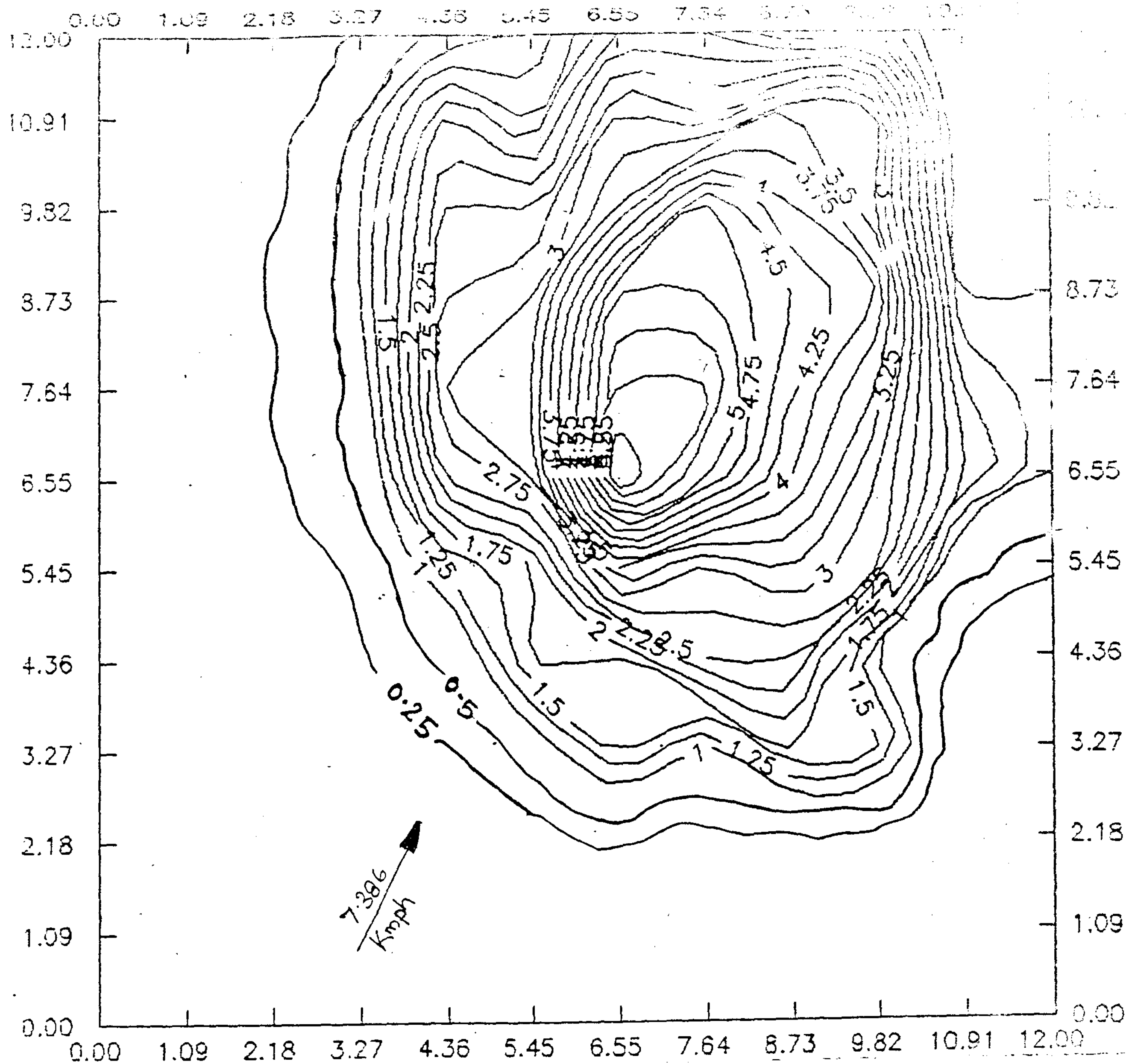


Fig.16 Water distribution pattern at 10% slope,
position: Perpendicular (Wind condition)

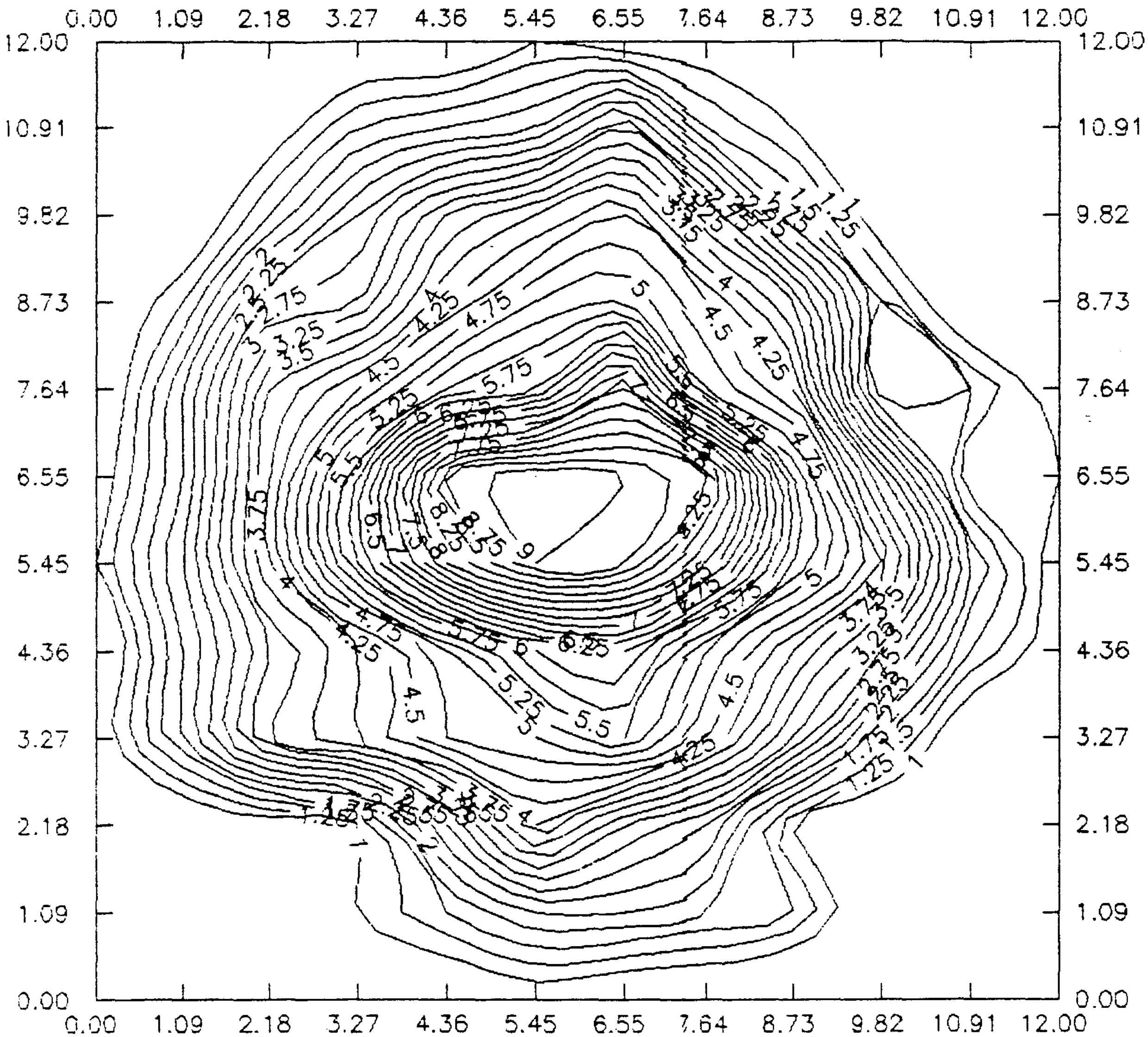


Fig.17 Water distribution pattern at 7.5% slope, Riser position: Vertical (No wind condition)

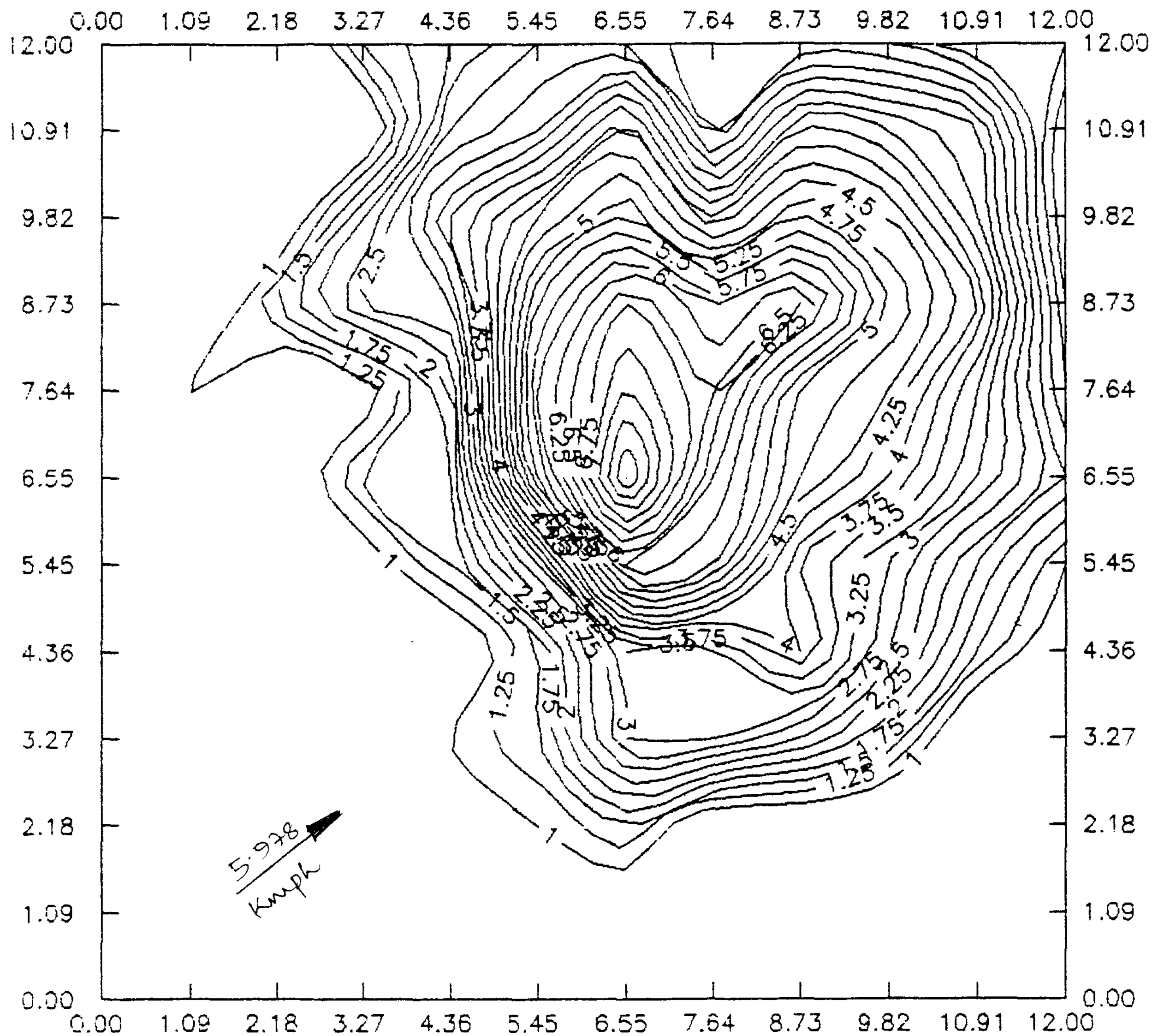


Fig.18 Water distribution pattern at 7.5% slope, Riser position: Vertical (Wind condition)

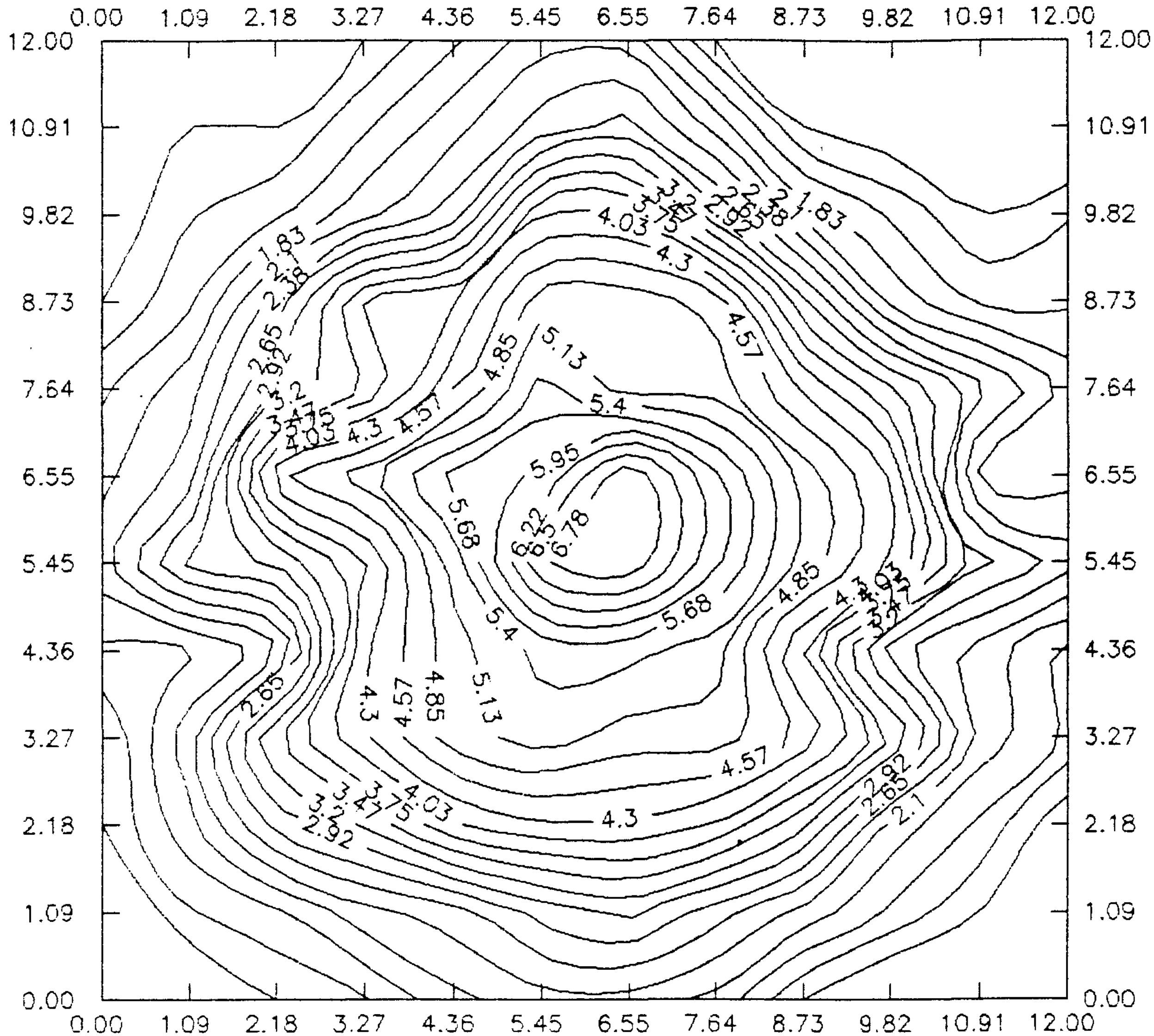


Fig.19 Water distribution pattern at 7.5% slope, Riser position: Midway (No wind condition)

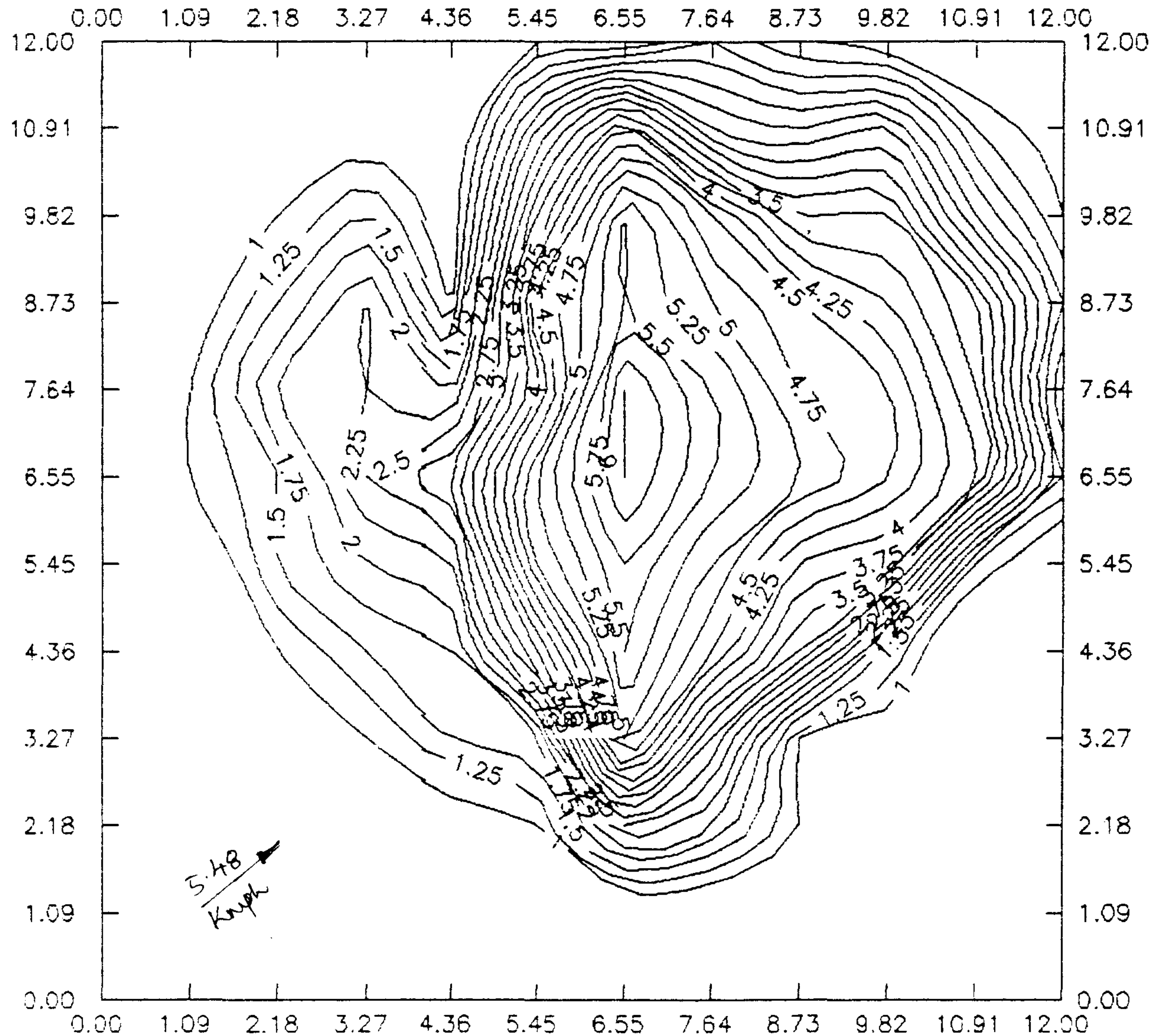


Fig.20 Water distribution pattern at 7.5% slope, Riser position: Midway (Wind condition)

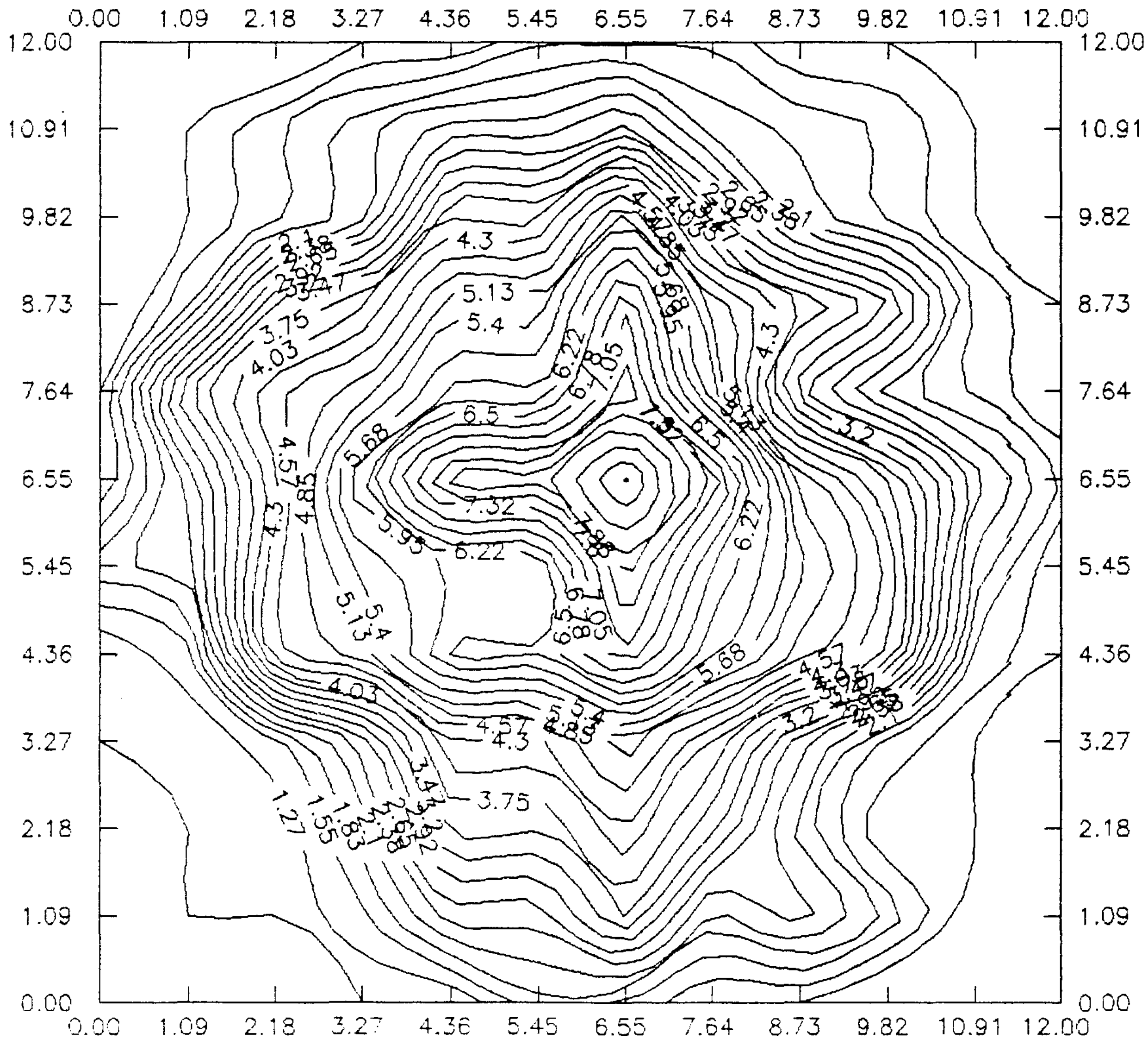


Fig.21 Water distribution pattern at 7.5% slope, Riser

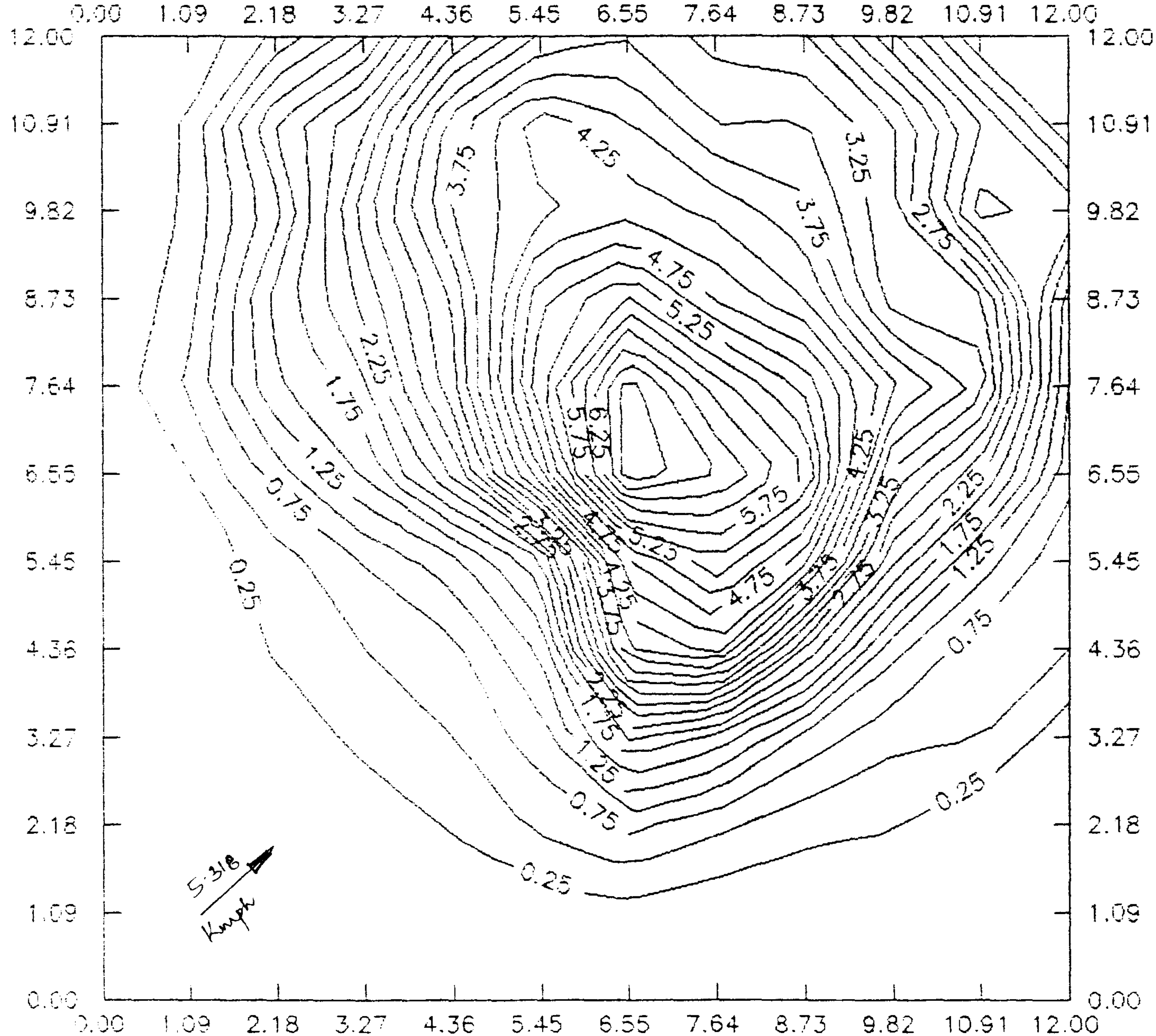


Fig.22 Water distribution pattern at 7.5% slope, Riser [illegible] Perpendicular (Wind condition)

uniformity was attained when the riser was in the perpendicular position and the same could be traeted as the optimum riser position for uniform water distribution. The optimum riser angles are found to be 7°7'30'' for 12.5 % slope, 5° 42'38'' for 10.0 % slope and 4°17'21'' for 7.5 % slope with respect to the vertical position.

The spacing of the sprinkler heads for uniforrm water distribution was also calculated for the various slopes and riser positions. The coefficient of uniformity was also calculated for different conditions. It was found that in normal conditions the spacing of the sprinkler can be upto 10m for uniform water distribution. The Cu values were 85.3%, 84.2% and 81.7%.

In perpendicular position the uniformity of water distribution was almost like that of normal condition. But the spacing was found to be between 10m and 9m. The Cu values were 83.5%, 80.2% and 87.6%. In mid way position the required spacing was in the range of 9m to 7m. Cu values were 86.8%, 85.3% and 84.1%. In the case of vertical position the spacing was between 8m and 6m in vertical position. The Cu values were 86.5%, 84.3% and 80.7%.

In all the cases it was found that the spacing of the sprinklers should be much closer for uniform distribution of water in wind conditions. The range of spacing should be between 5m and 4m in most of the cases. The Cu values were

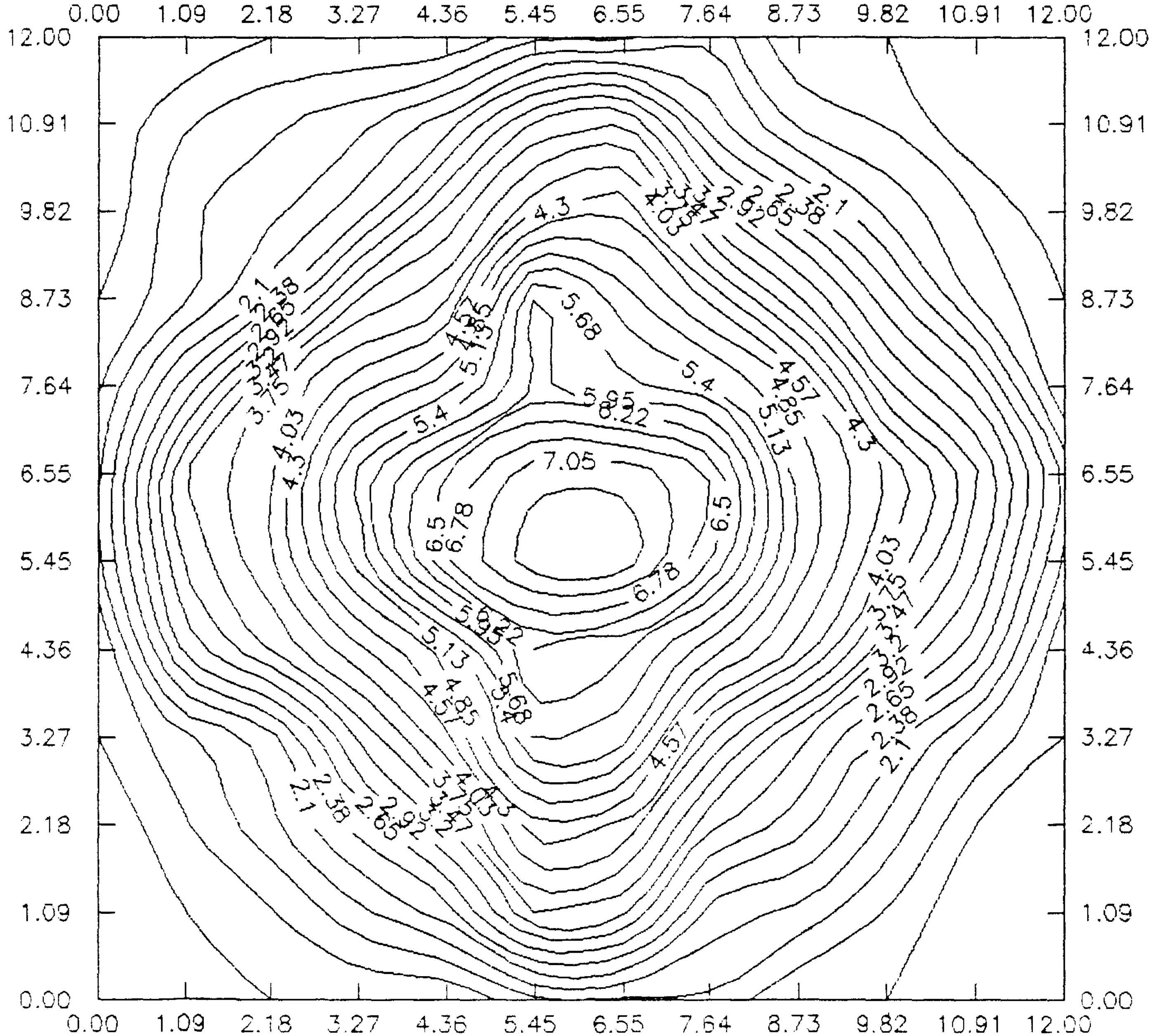


Fig.23 Water distribution pattern in no slope condition (No wind condition)

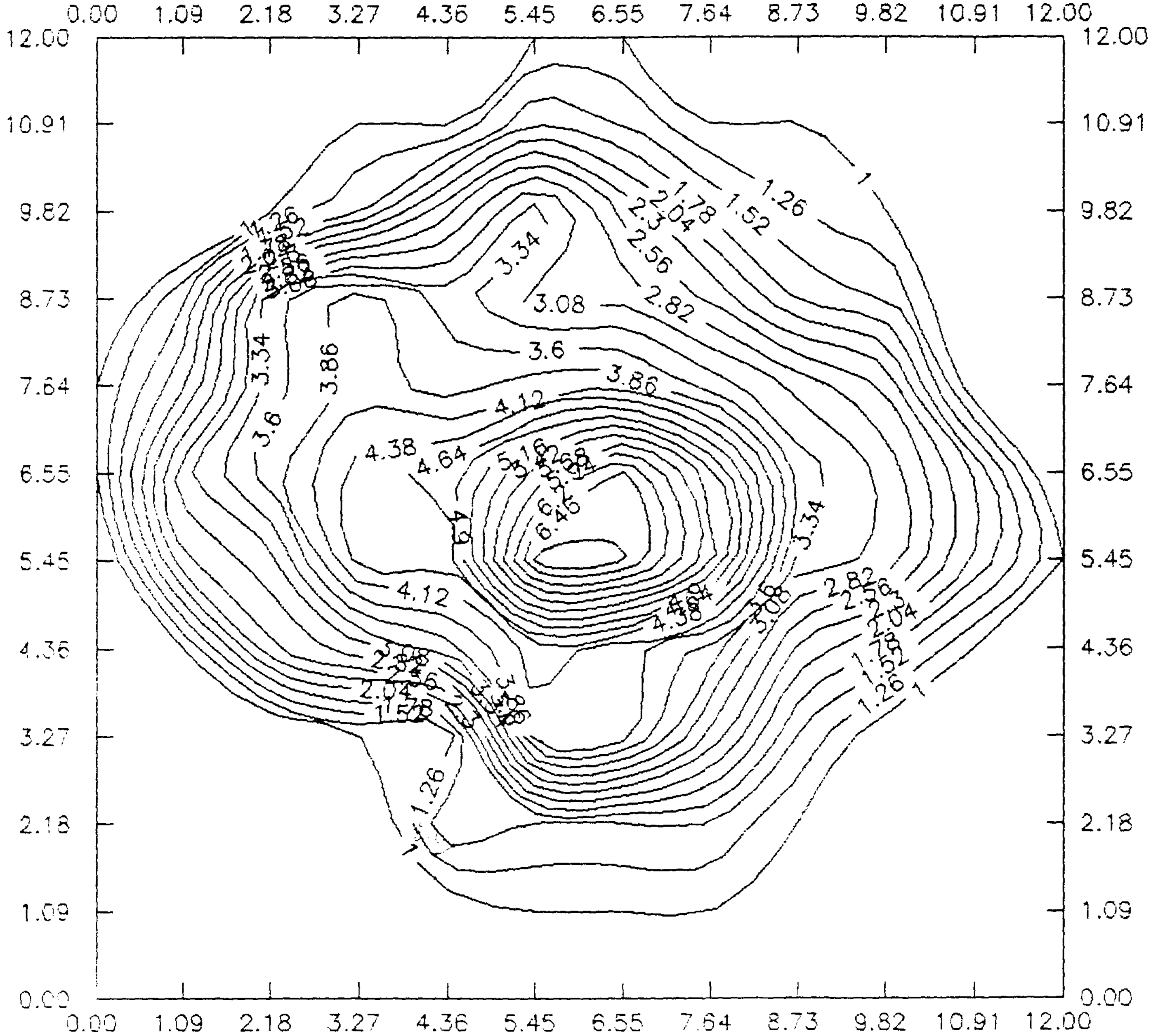


Fig.24 Water distribution pattern in no slope condition (Wind

ranging from 80% to 85%. The percentage of overlap required was upto 65.0 %.

4.4 Rotation rate of sprinkler head

The time taken by the sprinkler head for one rotation was plotted against the land slopes for different wind conditions and are shown from Fig.25 to Fig.31. It was found that for the vertical position of the riser the time taken by the sprinkler for one rotation was almost same in all the three cases. But as the riser position changes from vertical to perpendicular the time taken for one rotation was increased. It was found that the time taken for covering the upward half of the slope was lesser than the downward half in all the cases. In wind conditions the time taken for one rotation was more in every cases as the wind was having an impact against the direction of rotation of the sprinkler.

From the study it was found that the rpm was more in the case of vertical riser position. The rpm was decreasing as the riser position changes from vertical to perpendicular. It was also found that the rpm was less in no wind condition than in wind condition. The difference in time taken for covering the upper half of the land and the downward half may due to the unbalanced weight of the sprinkler head.

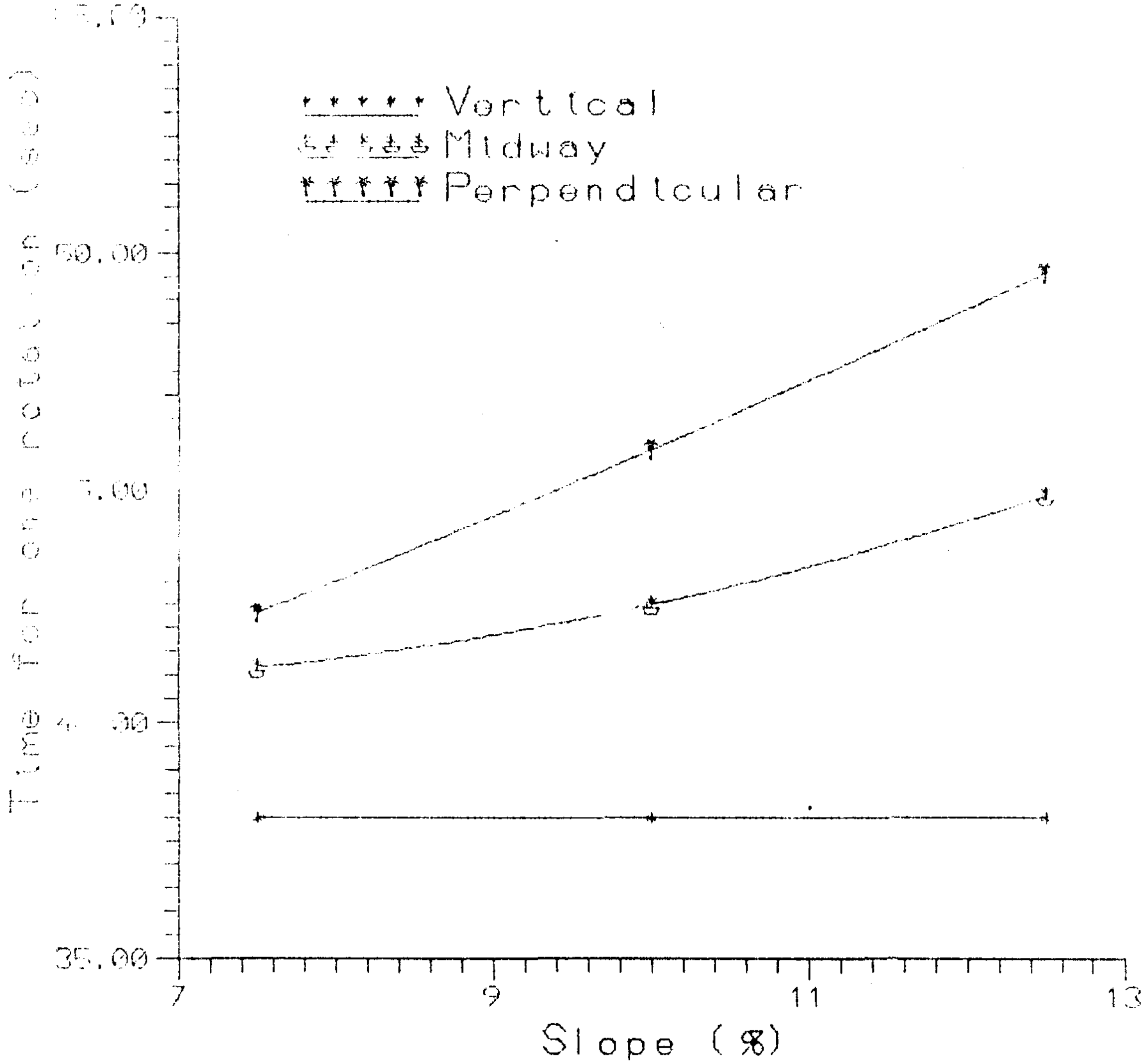


Fig. 25 Rotation rate of Sprinkler in no wind condition for different riser positions

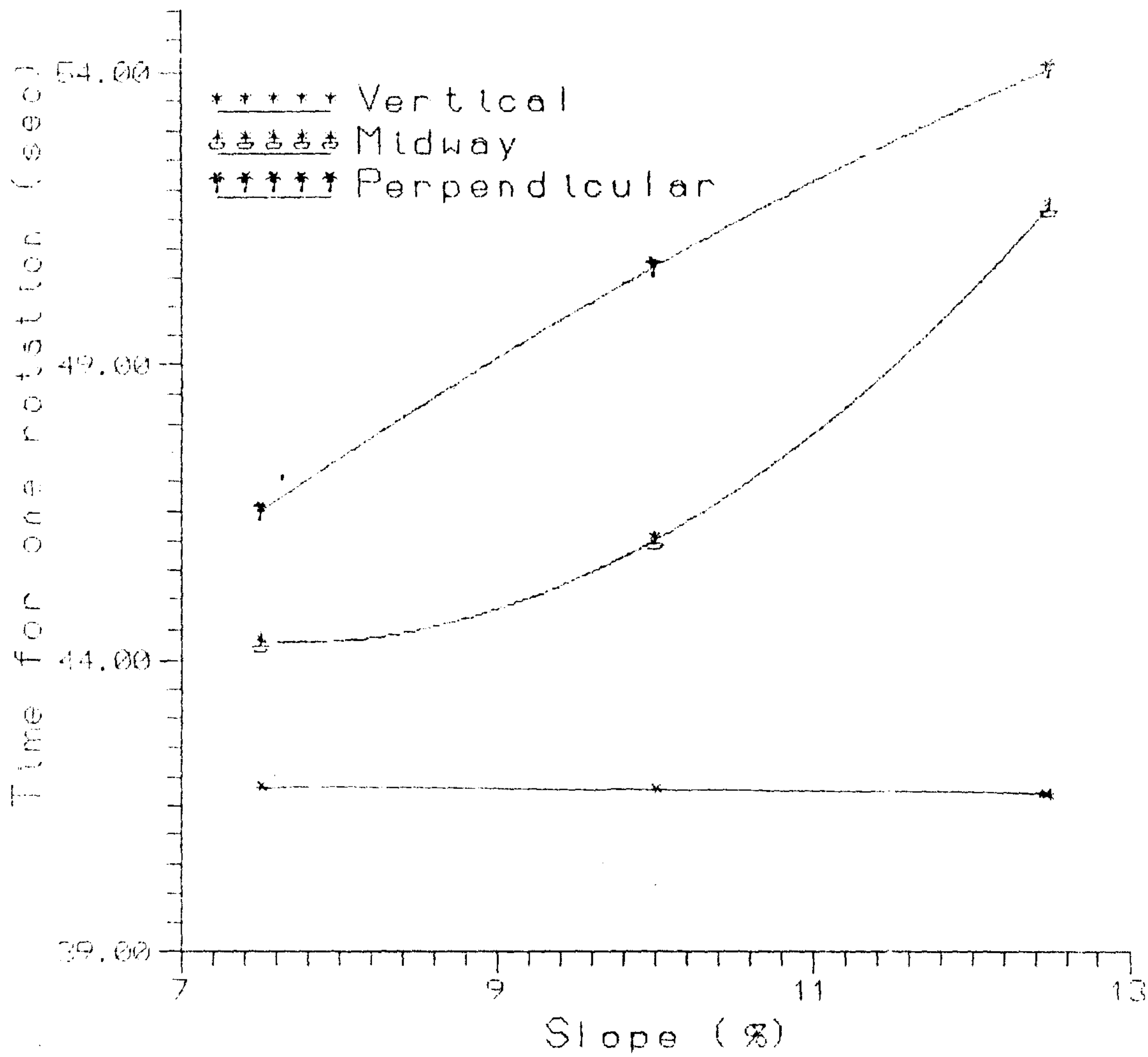


Fig.26 Rotation rate of Sprinkler in wind condition for different riser positions

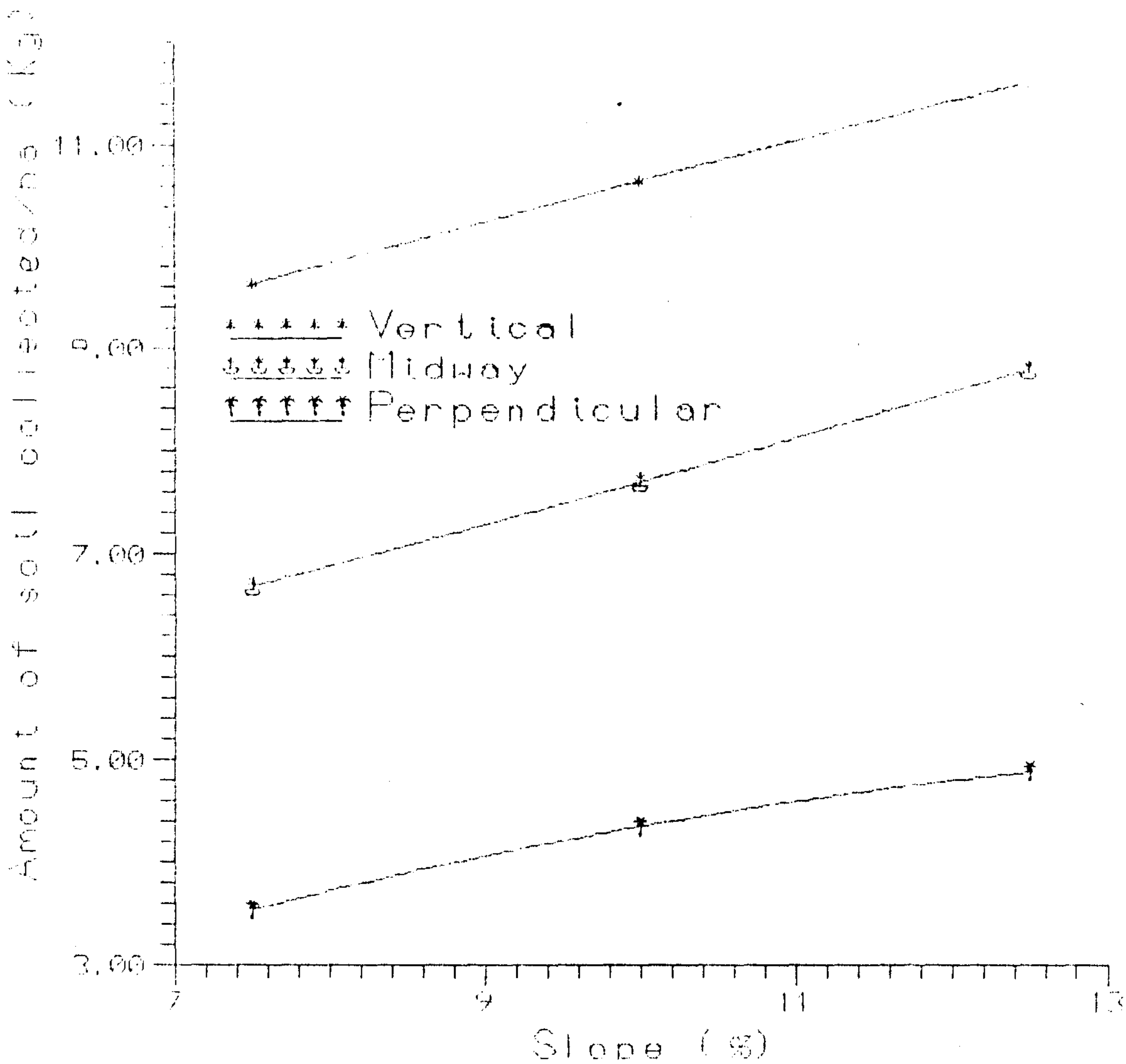


Fig.27 Erosion measurement for different riser positions.

4.5 Erosion measurement

Figure 32 to Fig.34 show the amount of soil collected against slopes for different riser positions. The amount of soil collected was more in the vertical position. It was less in midway position and least in the perpendicular position for all the three slopes. This may be due to the difference in impact energy of the water drops with respect to the change in riser positions. It was also observed that the erosivity was decreasing as the land slope was decreasing.

Summary

SUMMARY AND CONCLUSION

Sprinkler irrigation is one of the most widely used irrigation methods on sloping lands of Kerala. Uniformity of water distribution, good application efficiency, limited erosion, relatively low labour requirement and practicability of use on various soils and for difficult topographic conditions are attributes that make sprinkler irrigation attractive. With the general objective of studying the effect of land slope on sprinkler uniformity a study was conducted at K.C.A.E.T, Tavanur.

The experiment was conducted on an artificially made platform having an area of 12m * 12m. Catch cans were provided at 1m interval to collect the water. A single nozzle sprinkler was kept at the centre with the help of a GI riser pipe having a height of 1.5m. The experiment was carried out for three slopes viz; 12.5 %, 10.0 % and 7.5 %. The test was conducted also forplane land condition. The performance of the sprinkler was noted both in wind and no wind conditions. The rpm of the sprinkler head in different conditions were noted. The amount of soil detatched during the operation of the sprinkler was also noted. All these experiments were conducted for three riser positions viz; vertical, mid way between vertical & perpendicular and perpendicular to the land. The data were analysed with the help of a computer software packagenamely `SURFER'. The analysis of the experimental results evolved the following conclusions.

1. The uniformity of water distribution is decreasing as the slope of the land is increasing.

2. In sloping conditions the spacing of the sprinklers will be less than in normal conditions for uniform distribution of water. The per centage of overlap is to be increased in sloping lands compared to normal conditions.

3. In normal conditions the spacing of the sprinklers can be of 10m for uniform distribution. In these cases the uniformity coefficient ranges from 85% to 80%. For getting 100% uniformity the overlap recommended is 30 % to 35 %.

4. In no wind conditions as the land slope increases the spacing of the sprinklers could be decreased for uniform distribution. The spacing can be increased by changing the riser position from vertical to perpendicular. Wider spacing can be attained by keeping the riser in perpendicular position. The perpendicular position is the ideal position for uniform water distribution with maximum spacing of sprinklers in sloping lands.

5. In perpendicular position the spacing of the sprinklers can be between 10m and 9m for uniform water distribution in all the three slopes. The uniformity coefficient ranges from 80% to 88% in these cases. The percentage of overlap recommended is between 30 % and 40 %.

6. In mid way position the spacing of the sprinklers can be between 9m and 7m. The Cu values ranges from 80% to 87%. The recommended percentage of overlap ranges from 35 % to 45 %.

7. In vertical condition of the riser, the spacing between the sprinklers can be between 8m and 6m. The uniformity coefficient ranges from 80% to 86% and the percentage of overlap recommended is between 40 % and 50 %.

8. In wind conditions the spacing of the sprinklers is to be reduced more in sloping lands for all the riser positions for uniform water distribution. In such conditions the spacing ranges from 5m to 4m and the Cu values are 80% to 85%. The recommended overlap is upto 65 % in wind conditions for good water distribution.

9. The optimum riser angles for uniform distribution of water are 7°7'30'' for 12.5 % slope, 5°42'38'' for 10.0 % slope and 4°17'21'' for 7.5 % slope with respect to the vertical position.

10. The rpm of the sprinkler head was less in wind conditions than in no wind conditions for all the slopes and riser angles.

11. The time taken for covering the two halves of the sloping land was different in mid way and perpendicular riser positions. It was almost same in vetical position for all the slopes.

12. The amount of soil collected due to erosion was increasing as the slope of the land was increasing. The amount was more in vertical position, less in mid way position, and least in perpendicular position for all the slopes.

References

REFERENCES

*Allen, R.G. (1985). Sprinkler irrigation project design with production functions. *J. of I&D Engg.* **112**(4): 305-321.

*Arshad Ali, S.M. (1974). Procedure for sprinkler distribution testing for research purpose. *Transactions of the ASAE.* **37**(8): 325-329.

Ayars, J.E., Hutmacher, R.B., Schoneman, R.A. and Dettinger, D.R. (1993). Influence of cotton canopy on sprinkler irrigation uniformity. *Transactions of the ASAE* **34**(3): 890-896.

Bindu, P.K., George, M.K., Sreevidya, H. and Vishnu, B. (1992). Development and evaluation of a pulsating microsprinkler irrigation system. *Unpulished B.Tech project report submitted to KAU, Vellanikkara.*

*Boman, J.B. (1989). Distribution pattern of selected emitters used for micro irrigation of Florida citrus. *Transactions of the ASAE* **32**(4): 567-573.

Chang, W.J. and Hills, D.J. (1993). Sprinkler droplet effects on infiltration. *J. of I&D Engg* **119**(1): 142-156.

Chen, D. and Wallender, W.W. (1984). Economic sprinkler selection, spacing and orientation. *Transactions of the ASAE* **27**(3): 737-743.

*Chen, D and Wallender, W.W. (1985). Droplet size distribution and water application with low pressure sprinklers. *Transactions of the ASAE* **28**(2): 511-516.

*Christiansen, J.E. (1942). Irrigation by sprinkling. *Agrl. Engg.* pp. 533-538.

*Cook, F.J. (1983). Water distribution over the soil surface and within the soil during sprinkler irrigation. *New Zealand J. of experimental agricultuer* **11**: 69-72.

Dhotrey, R.S., Suryawanshi, S.N. and Pampattiwar, P.S. (1985). Evaporation losses during sprinkling. *Proceedings of Silver Jubilee Convention ISAE* II :53-59.

Elliot, R.L., Nelson, J,D. Loftis, J.C. and Hart W.E. (1980). Comparison of sprinkler uniformity models. *J. of I&D Division* **106**(IR4): 321-329.

*English, M. Taylor, A. and John, P. (1986). Evaluating sprinkler system performance. *New Zeland Agric. Sciences* **20**(1): 32-38.

Finkel, Herman, J. (1982). *CRC Hand Book of Irrigation Technology.* Vol.I CRC Press Inc. Boca Ration, Florida. pp.193-245.

*Fisher, G.R. and Wallender, W.W. (1988). Collector size and test duration effects on sprinkler water distribution measurement. *Transactions of the ASAE* **31**(2): 538-542.

*Frost, K.R. and Schwalen, H.C. (1956). Sprinkler evaporation losses. *Agrl. Engg.* **36**(8): 526-528.

Grant, T.W., Anderson, W.C. and Rochestor, E.W. (1984). Constant and variable operating angle sprinklers for travelor irrigators. *Transactions of the ASAE* **27**(4): 1106-1110.

Han, S., Evans, R.G. and Kroger, M.W. (1994). Sprinkler distribution pattern in wind conditions. *Transactions of the ASAE* **37**(5): 1481-1489.

*Hills, D.J. (1984). Sprinkler volume mean droplet diameter as a function of pressure. *Transactions of the ASAE.* **27**(4): 535-542.

*Hussain, M. (1992). Losses from low pressure centre pivot irrigation systems in a desert climate as affected by nozzle height. *Agric. water management* **21**: 23-32.

Kay Melvyn (1983). *Sprinkler irrigation equipment and practice.* ELBS Publishing Co. London. Kincaid, D.C. (1982). Sprinkler pattern radius. *Transactions of the ASAE* **25**(6): 166 -1672.

Kincaid, D.C. (1991). Impact sprinkler pattern modification. *Transactions of the ASAE* **34**(6): 646-651.

*Kohl, R.A. (1974). Drop size distribution for medium sized agricultural sprinklers. *Transactions of the ASAE.* **10**(7): 717-723.

Kohl, R.A. (1984). Droplet size distribution for a low pressure spray type agricultural sprinkler. *Transactions of the ASAE* Paper No: 83-2019.

Koluvek, P.K., Tanj, N.K. and Trout, T.J. (1993). Overview of soil erosion from irrigation. *J. of I&D Engg.* 929-926.

*Kraus, J.H. (1961). Application efficiency of sprinkler irrigation and its effect on microclimate. *Transactions of the ASAE* **9**(5): 642-649.

Li, J., Kawano, H. and Yu, K.(1994). Droplet size distribution from different shaped sprinkler nozzles. *Transactions of the ASAE* **14**(4): 103-110.

Michael, A.M. (1978). *Irrigation Theory and Practice.* Vikas Publishing House Pvt. Ltd. Delhi pp : 448 - 685.

Pair, C.H. (1968). Water distribution under sprinkler irrigation. *Transactions of the ASAE* **38**(7): 646-651.

*Park, S.H. (1980). Splash erosion modelling, Physical analysis. *Transactions of the ASAE* **80** - 2502.

*Richard, H.C. (1989). *Irrigation system design an Engineering approach.* Prentice Hall, Eagle wood cliffs, New Jercy.

Sanchez, C.A., Rooth, R.L. and Gander, B.R. (1994). Irrigation and nitrogen management for sprinkler irrigated cabbage on sand. *J. of American society for Agrl. Sciences* **119**(3): 427-433.

*Schultz, J.P. (1985). Detatchment and splash of a cohesive soil by rain fall. *Transactions of the ASAE* 84 - 202.

Seginer, I. (1965). Tangential velocity of sprinkler drops. *Transactions of the ASAE* **21**(5): 90-93.

Seginer, I., Kantz, D. Nir, D. and Von Bermuth, R.D. (1992). Indoor measurement of single radius sprinkler pattern. *Transactions of the ASAE* **40**(5): 428-435.

Selvan, P. and Elavana, S. (1990). Performance evaluation of sprinkler heads. *Unpublished B.Tech Project Report Submitted to KAU, Vellanikkara*.

Sivanappan, R.K. (1985). Status report on sprinkler irrigation in India. *Proceedings of Indian National Committe on I&D,* New Delhi.

Sivanappan, R.K. (1987). *Sprinkler Irrigation.* Oxford and IBH Publishing Co. Pvt. Ltd. Calcutta.

Soares, A.A., Williardson, L.S. and Keller, J. (1991). Surface slope effects on sprinkler uniformity. *J. of I&D Engg.* **117**(6): 870-879.

*Trimmel, W.L. and Perkins, W.A. (1987). Irrigation efficiency of centre pivot sprinklers. *Paper of ASAE* No : 87 2594 13 pp.

Trout, T.J. (1993). Erosion and sedimentation process on irrigated fields. *J. of I&D Engg.* **119**(6): 947-963.

Tsakiris, G.P., Terzis, G.C. and Karakos, A.S. (1985). A Pearson distribution model describing sprinkler irrigation efficiency. *Agric. Water Management* **9**: 325-337.

Von Bernuth, R.D. (1984) Sprinkler droplet size distribution estimation from single leg test data. *Transactions of the ASAE* **23**(1): 1435-1441.

Von Bernuth, R.D. (1988). Effect of trajectory angle on performance of sprinkler in wind. *J. of I&D Engg.* **114**(4): 579-589.

*Williardson, L.S. (1971). High rate sprinkling of a low intake soil. *Transactions of the ASAE.* **27**(3): 1010-1017.

*Wiser, E.H., Schilfgaarde, J.V. and Wilson, T.V. (1961). Evapotranspiration concepts for evaluating sprinkler irrigation losses. *Transactions of the ASAE* **4**(1): 128-135.

Wu, I.P. and Gitlin, H.M. (1983). Sprinkler irrigation design for uniformity on slopes. *Transactions of the ASAE* **26**(6): 1698-1703.

*Yasin, H.I., Jajor, N.M. and Hussan, Y.M. (1988). Effect of sprinkler heads arrangement on uniformity of water distribution. *J. of Agric. Water Resources Res. Soil Water Resources* 7(2): 267-273.

* Originals not seen

Appendices

R Appendix :1

Table 2. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle 0
no wind condition
riser position : vertical

0.00	0.50	0.25	0.50	1.75	2.00	3.00	2.50	1.50	1.00	0.75	0.00	0.00
0.25	0.75	0.50	1.75	4.00	3.50	3.75	3.50	3.50	2.00	0.75	0.00	0.00
0.25	0.25	0.50	3.00	5.00	6.00	7.75	4.25	4.50	2.50	0.75	0.25	0.00
0.50	0.25	0.50	3.00	5.75	7.00	8.50	6.25	6.00	4.50	1.75	0.50	0.25
0.25	0.25	1.25	3.50	6.50	9.00	9.50	8.50	7.00	7.00	4.00	1.00	0.25
0.25	0.50	1.25	6.50	8.75	9.00	9.50	9.00	7.50	6.09	5.00	1.50	0.50
0.25	0.50	0.75	1.75	3.25	4.25		5.50	3.00	2.50	1.75	0.50	0.50
0.00	0.25	0.25	1.50	1.75	3.25	3.75	3.50	2.00	2.00	1.50	0.50	0.25
0.00	0.00	0.25	1.25	1.75	2.25	2.50	3.00	1.75	1.75	0.50	0.25	0.25
0.00	0.25	0.25	0.50	1.50	1.75	2.00	2.50	1.50	1.50	0.50	0.25	0.00
0.00	0.00	0.25	0.50	0.75	1.50	1.50	1.00	0.50	0.25	0.25	0.00	0.00
0.00	0.00	0.00	0.50	0.75	1.00	1.00	1.00	0.50	0.25	0.25	0.00	0.00
0.00	0.00	0.00	0.25	0.50	0.50	1.50	0.75	0.50	0.25	0.00	0.00	0.00

R Appendix :2

Table 3. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle :0
wind condition   wind speed : 6.042 kmph
riser position : vertical

0.00	0.00	0.00	0.25	1.50	2.00	2.25	3.25	2.50	2.00	1.00	0.25	0.00
0.00	0.00	0.00	0.50	1.50	2.50	3.00	4.00	3.00	3.25	1.50	0.50	0.25
0.00	0.00	0.00	0.50	2.00	3.00	4.00	4.00	4.25	4.00	2.00	0.75	0.75
0.00	0.00	0.25	0.75	2.50	3.25	4.50	4.50	5.00	5.00	2.00	1.00	0.75
0.00	0.00	0.25	1.00	2.00	3.50	5.00	6.00	6.00	5.25	3.25	1.25	1.00
0.00	0.00	0.25	1.50	1.00	3.00	5.50	5.75	6.00	5.00	2.50	0.75	0.50
0.00	0.00	0.25	2.00	0.75	2.25		4.50	5.50	3.75	1.75	0.50	0.50
0.00	0.00	0.25	1.75	0.50	1.75	5.50	3.00	5.25	3.00	1.50	0.50	0.25
0.00	0.00	0.25	0.75	0.50	1.75	5.00	2.50	4.75	2.50	0.50	0.25	0.25
0.00	0.00	0.00	0.25	0.25	1.00	4.50	1.50	3.00	1.50	0.25	0.25	0.25
0.00	0.00	0.00	0.00	0.25	0.50	2.50	0.50	1.00	0.75	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	1.00	0.25	0.50	0.25	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

R Appendix : 3

Table 4. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle : 3 33'45''
no wind condition
riser position : midway

0.00	0.00	0.50	0.75	0.75	1.00	0.75	0.50	0.50	0.25	0.00	0.00	0.00
0.00	0.25	0.25	0.50	0.75	1.00	1.75	2.00	1.75	1.50	0.50	0.00	0.00
0.00	1.00	1.25	1.50	1.50	3.00	3.00	3.50	3.25	1.50	0.50	0.25	0.00
1.00	1.00	2.00	3.00	3.50	4.00	4.50	4.00	3.25	2.50	1.00	0.50	0.25
1.50	1.50	2.00	3.00	5.50	6.00	6.50	8.80	6.00	5.50	4.75	2.50	1.00
1.50	2.00	4.00	6.50	7.50	7.50	8.00	8.50	6.50	6.00	5.50	3.00	1.00
1.50	2.00	5.00	6.50	7.00	7.50		7.00	6.50	5.00	4.50	2.00	0.75
1.00	3.00	4.25	5.50	6.50	6.75	7.25	6.00	6.00	5.25	4.00	1.50	1.00
0.50	1.50	2.50	3.75	4.50	5.00	5.50	5.00	4.00	3.25	3.00	1.25	0.75
0.25	1.00	2.00	3.00	3.25	4.25	4.75	4.00	3.50	3.50	2.00	1.25	0.50
0.00	0.25	1.00	1.50	2.75	3.00	3.75	3.00	2.50	2.25	1.00	0.75	0.00
0.00	0.00	0.25	0.50	1.00	1.75	2.00	2.00	1.75	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.50	0.50	0.75	1.00	1.00	0.75	0.50	0.00	0.00	0.00

R Appendix : 4

Table 5. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle : 3 33'45''
wind condition   wind speed : 3.945 kmph
riser position : midway

0.00	0.00	0.25	1.50	2.00	2.00	3.00	1.00	1.00	0.75	0.25	0.25	0.25
0.00	0.00	1.00	1.50	2.50	2.50	3.00	1.75	2.00	1.50	1.25	0.50	0.50
0.00	0.00	1.50	2.00	3.00	3.00	4.00	4.25	3.50	3.00	3.25	3.00	1.00
0.00	0.25	2.00	2.75	3.25	4.25	4.50	5.00	4.75	4.00	4.50	3.50	1.50
0.00	0.25	1.75	2.50	3.50	4.50	5.50	6.00	5.00	4.50	5.00	4.00	1.50
0.00	0.25	0.75	3.00	3.00	5.00	5.50	6.00	5.25	4.50	4.25	3.00	1.00
0.00	0.25	0.50	1.00	3.25	5.50		4.25	3.50	3.75	4.00	1.50	1.00
0.00	0.00	0.25	0.75	2.75	4.25	5.00	3.75	3.25	3.25	2.00	1.25	0.25
0.00	0.00	0.25	0.50	1.75	3.00	3.00	2.50	1.50	3.00	2.50	0.50	0.25
0.00	0.00	0.25	0.50	1.00	1.50	2.00	2.00	0.50	1.50	1.00	0.25	0.00
0.00	0.00	0.00	0.25	0.50	0.50	2.50	1.00	0.25	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.25	0.50	0.25	0.50	0.25	0.25	0.25	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

R Appendix : 5

Table 6. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle : 7 7'30''
no wind condition
riser position : perpendicular

0.00	0.00	0.25	0.25	0.50	0.75	1.00	0.75	0.75	0.50	0.25	0.00	0.00
0.00	0.00	1.50	1.50	1.75	1.00	3.25	1.50	1.50	1.00	0.75	0.00	0.00
0.25	0.50	2.50	3.00	3.50	2.00	4.75	3.25	3.25	1.75	1.50	0.50	0.00
0.50	1.25	3.00	3.25	4.25	4.00	5.00	4.50	4.50	3.50	1.75	1.00	0.50
0.50	2.00	4.50	4.75	5.50	5.00	6.75	5.00	5.00	4.00	3.25	1.50	0.75
0.75	2.00	4.75	5.00	6.75	6.00	7.00	7.00	6.00	4.25	4.50	3.00	1.00
1.00	3.00	5.00	5.50	6.50	7.25		7.00	6.00	5.50	4.00	3.00	1.00
1.00	2.25	4.50	5.00	6.00	7.00	7.25	7.25	5.50	5.00	4.25	2.00	0.75
0.50	2.00	4.00	4.00	5.00	5.00	6.00	6.25	4.00	4.00	3.00	1.50	0.75
0.75	2.00	3.00	3.75	4.75	4.00	5.50	5.50	3.25	3.25	1.75	0.50	0.25
0.25	0.50	1.00	2.50	2.50	2.00	5.00	3.00	1.50	1.50	0.50	0.25	0.00
0.00	0.00	1.00	1.50	1.50	1.00	3.00	1.00	1.00	1.00	0.50	0.00	0.00
0.00	0.00	0.25	0.50	0.50	0.75	1.00	0.50	0.50	0.25	0.00	0.00	0.00

R Appendix : 6

Table 7. Quantity of water collected in the catch cans (ml)
slope : 12.5 %   riser angle : 7 7'30''
wind condition   wind speed : 6.336 kmph
riser position : perpendicular

0.00	0.00	0.25	0.75	1.75	2.50	4.50	3.00	2.25	1.00	1.00	0.75	0.50
0.00	0.00	0.50	1.50	2.75	4.00	5.50	4.00	3.50	2.00	2.50	0.75	0.75
0.00	0.00	0.75	1.75	3.50	5.00	6.00	5.50	4.00	3.00	3.00	1.00	1.00
0.00	0.50	1.00	2.50	4.75	6.25	6.75	6.50	5.25	4.00	3.50	1.50	1.00
0.00	0.25	1.50	2.50	5.75	6.00	7.00	6.75	5.50	5.00	4.00	2.00	3.00
0.00	2.75	1.75	3.00	4.50	5.75	7.00	7.00	5.00	5.50	4.75	3.50	2.50
0.00	0.50	2.50	3.00	4.00	5.00		6.00	4.75	3.50	3.00	2.50	2.00
0.00	0.50	1.50	2.25	2.50	4.50	6.00	5.00	3.00	2.50	2.00	2.00	1.50
0.00	0.00	0.25	1.25	1.75	4.00	5.50	5.00	2.00	1.50	1.50	0.50	0.50
0.00	0.00	0.00	0.25	1.50	3.50	4.25	3.00	1.50	0.50	0.50	0.25	0.25
0.00	0.00	0.00	0.00	0.25	1.75	1.25	0.50	0.50	0.25	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

R Appendix : 7

Table 8. Quantity of water collected in the catch cans (ml)
slope : 10.0 %   riser angle : 0
no wind condition
riser position : vertical

0.00	0.00	0.25	0.50	0.75	1.00	1.00	1.00	0.75	0.50	0.25	0.25	0.00
0.00	0.25	0.25	0.50	1.50	2.50	3.00	2.00	1.75	0.50	0.25	0.50	0.00
0.25	0.25	0.50	1.25	2.50	3.00	4.00	3.00	2.75	1.00	0.50	1.00	0.25
0.50	0.50	1.00	1.75	3.75	4.00	5.25	4.00	3.50	1.25	1.00	1.00	0.25
0.50	0.75	1.50	2.00	3.00	4.50	5.50	5.25	3.50	1.50	1.00	1.25	0.50
0.50	1.00	1.50	2.25	3.25	5.00	5.75	5.50	3.25	2.00	1.50	1.75	0.75
0.25	1.00	1.25	2.50	3.75	4.50		4.75	3.00	2.25	1.00	1.50	0.75
0.25	0.50	1.00	1.75	2.75	4.00	4.50	4.00	2.50	2.00	1.00	1.50	0.50
0.25	0.50	0.75	1.50	2.50	3.00	4.25	3.25	2.25	1.50	1.25	1.25	0.25
0.25	0.25	0.50	1.00	1.75	2.00	3.50	2.00	1.50	1.00	0.50	0.50	0.25
0.00	0.25	0.25	0.50	0.75	1.50	2.00	1.75	0.50	0.75	0.25	0.25	0.00
0.00	0.00	0.00	0.25	0.50	1.00	1.00	0.50	0.50	0.50	0.25	0.25	0.00
0.00	0.00	0.00	0.25	0.25	0.50	0.50	0.25	0.25	0.25	0.00	0.00	0.00

R Appendix : 8

Table 9. Quantity of water collected in the catch cans (ml)
slope : 10.0 %   riser angle : 0
wind condition   wind speed : 2.15 kmph
riser position : vertical

0.00	0.00	0.25	0.50	0.75	1.00	1.50	1.00	1.00	0.75	0.75	0.75	0.25
0.00	0.00	0.25	0.75	1.00	1.50	2.00	3.75	2.00	1.50	1.50	1.00	0.50
0.00	0.25	0.50	1.00	1.50	2.50	3.50	4.00	3.50	3.25	2.00	1.50	1.50
0.25	0.50	0.50	1.50	1.75	3.00	5.00	6.00	4.25	4.25	2.50	2.25	2.25
0.25	0.50	0.75	2.00	2.00	4.50	6.00	6.25	5.50	5.50	3.00	3.00	2.50
0.25	0.50	0.75	1.75	2.00	5.00	7.25	7.00	6.25	5.00	3.75	3.50	3.25
0.00	0.50	0.75	1.75	1.50	3.00		5.00	6.00	3.50	3.25	3.25	3.00
0.00	0.25	0.50	1.50	1.00	1.50	5.00	4.00	4.25	2.50	2.50	1.50	2.00
0.00	0.25	0.25	0.75	0.75	1.00	3.00	3.00	4.00	1.00	1.50	1.00	1.50
0.00	0.25	0.25	0.50	0.50	0.75	2.50	2.00	3.00	0.75	0.75	0.50	0.75
0.00	0.00	0.25	0.50	0.50	0.75	2.25	1.00	1.50	0.50	0.25	0.25	0.50
0.00	0.00	0.00	0.25	0.25	0.50	0.75	0.25	0.50	0.25	0.00	0.00	0.00
0.00	0.00	0.00	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00

R

Appendix : 9

Table 10. Quantity of water collected in the catch cans (ml)
slope : 10.0 %   riser angle : 2 51'19''
no wind condition
riser position : mid way

0.00	0.00	0.25	1.00	1.00	1.50	1.50	1.00	1.25	0.50	0.25	0.00	0.00
0.00	0.25	1.00	2.50	2.00	4.00	4.00	1.25	1.50	1.00	0.50	0.25	0.00
0.25	0.50	1.50	3.75	4.00	4.50	5.00	1.50	4.00	2.75	1.75	1.00	0.50
0.50	0.50	2.25	5.00	5.25	5.75	6.25	4.00	5.00	4.00	2.00	2.00	0.75
1.00	0.75	3.50	5.50	5.50	6.00	6.50	5.00	5.50	5.25	3.50	3.50	1.00
1.50	1.50	4.50	5.25	5.75	6.50	7.00	6.25	5.75	5.50	4.25	3.50	1.50
1.50	1.75	5.00	4.25	5.25	6.25		6.50	6.00	5.00	4.75	2.00	1.50
1.00	1.50	2.75	2.50	4.00	5.25	6.50	5.00	5.50	4.00	2.50	1.00	1.00
0.50	1.00	1.50	2.00	2.25	4.00	6.00	3.25	3.50	2.25	1.75	0.75	0.50
0.25	1.00	1.00	1.25	2.00	2.50	4.50	3.00	2.50	2.00	1.50	0.75	0.25
0.00	0.50	0.75	1.00	1.75	2.00	3.00	1.50	1.75	1.00	0.50	0.25	0.00
0.00	0.00	0.50	0.75	0.50	1.50	2.00	0.75	1.50	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.25	0.25	0.50	0.75	0.50	0.50	0.25	0.00	0.00	0.00

Appendix : 10

Table 11. Quantity of water collected in the catch cans (ml)
slope : 10.0 %   riser angle : 2 51'19''
wind condition   wind speed : 4.348 kmph
riser position : mid way

0.00	0.00	0.25	0.25	1.50	1.50	1.50	1.00	1.00	1.00	0.75	0.25	0.00
0.00	0.00	0.50	1.00	1.75	1.50	2.50	1.50	1.50	1.50	1.25	0.25	0.25
0.00	0.00	1.50	1.50	2.50	1.75	2.00	2.25	1.50	2.00	1.00	0.50	0.25
0.00	0.00	1.50	3.00	2.75	2.00	4.00	3.50	3.25	3.00	1.50	0.50	0.50
0.00	0.00	2.00	3.50	3.00	3.00	5.00	4.25	4.50	2.75	1.75	0.75	0.75
0.00	0.00	2.00	4.00	3.50	4.00	5.00	4.50	4.00	2.50	2.00	1.50	1.00
0.00	0.25	3.00	3.75	4.50	4.50		4.75	3.00	2.00	2.50	2.00	1.00
0.00	0.25	1.50	2.50	4.75	4.75	4.75	3.00	2.00	2.00	2.50	1.75	0.75
0.00	0.25	0.25	0.50	3.00	4.50	3.50	2.50	1.50	1.00	1.25	1.20	0.50
0.00	0.00	0.25	0.25	1.00	1.50	2.50	2.00	1.00	0.75	1.00	1.00	0.25
0.00	0.00	0.25	0.25	0.75	0.50	2.00	1.25	0.25	0.25	0.50	0.75	0.00
0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

R Appendix : 11

Table 12. Quantity of water collected in the catch cans (ml)
slope : 10.0 % riser angle : 5 42'38''
no wind condition
riser position : perpendicular

0.00	0.00	0.25	0.50	0.75	1.00	1.50	1.50	1.00	0.75	0.50	0.25	0.00
0.00	0.25	0.50	0.75	2.50	3.25	3.50	3.00	2.00	1.00	0.75	0.50	0.25
0.00	0.25	0.75	1.50	3.50	4.00	5.25	4.50	3.00	3.25	2.00	0.75	0.25
0.25	0.50	1.00	2.00	4.75	5.25	6.00	5.50	4.75	4.50	3.50	1.50	0.50
0.75	1.00	3.75	5.00	6.50	7.25	7.50	7.25	6.75	5.50	4.25	2.00	1.00
1.00	2.00	4.50	5.50	7.25	8.00	8.00	8.25	7.50	5.00	4.75	2.25	1.75
1.00	3.25	4.50	5.50	7.50	8.00		8.00	7.50	5.75	5.25	2.00	1.50
1.25	3.00	4.75	5.25	6.50	8.25	8.00	8.00	7.25	5.25	4.50	1.50	1.00
1.50	1.00	4.25	4.00	5.00	7.00	7.25	7.50	6.50	5.50	4.00	1.00	0.75
1.00	0.75	3.50	3.50	4.50	5.25	6.00	5.50	5.00	4.75	3.25	0.50	0.50
0.75	0.25	1.50	2.50	2.00	4.25	5.50	5.00	4.00	3.50	2.00	0.25	0.25
0.00	0.25	0.75	1.50	1.75	3.00	3.50	3.25	2.50	1.00	0.75	0.25	0.00
0.00	0.00	0.25	0.50	0.75	1.00	1.50	1.00	0.50	0.25	0.25	0.00	0.00

R Appendix : 12

Table 13. Quantity of water collected in the catch cans (ml)
slope : 10.0 % riser angle : 5 42'38''
wind condition wind speed : 7.386 kmph
riser position : perpendicular

0.00	0.00	0.00	0.00	0.50	0.50	1.50	1.75	1.00	1.00	1.00	0.50	0.25
0.00	0.00	0.25	0.00	0.75	0.75	1.75	2.00	2.00	1.50	1.00	0.75	0.25
0.00	0.00	0.25	0.25	1.25	1.00	2.50	4.00	3.00	3.00	1.00	1.00	0.25
0.00	0.00	0.50	0.25	1.50	2.00	4.25	4.50	4.00	4.25	2.50	1.50	0.50
0.00	0.00	0.50	1.50	2.00	3.50	5.00	5.50	4.50	4.50	3.00	2.00	0.75
0.00	0.00	0.50	1.50	1.50	3.50	6.00	5.50	5.00	4.75	4.00	2.00	1.00
0.00	0.00	0.25	0.75	1.50	2.50		5.00	4.50	5.00	3.50	2.50	1.00
0.00	0.00	0.25	0.50	1.50	1.50	4.00	4.50	4.00	4.00	2.50	2.00	0.50
0.00	0.00	0.00	0.25	1.00	0.75	3.00	3.00	3.50	2.00	1.50	1.50	0.25
0.00	0.00	0.00	0.25	0.75	0.50	1.00	1.50	2.50	1.00	0.75	0.50	0.00
0.00	0.00	0.00	0.00	0.25	0.25	0.50	0.25	0.75	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix : 13

Table 14. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 0
no wind condition
riser position : vertical

0.50	1.00	1.50	1.50	2.00	1.75	2.00	2.00	1.50	1.00	0.75	0.50
0.75	1.00	1.50	2.00	2.50	3.00	4.50	3.00	2.00	2.50	1.00	0.50
1.00	1.50	2.75	3.00	3.00	4.50	5.00	4.50	3.50	1.50	1.00	0.75
1.00	1.75	3.50	4.00	4.50	5.25	5.50	5.00	4.50	3.00	1.50	1.00
1.50	2.00	4.00	4.50	5.25	5.75	6.00	5.50	5.00	3.75	2.50	1.50
2.00	3.25	4.50	4.75	6.00	7.00	8.75	7.00	6.00	4.50	3.50	2.00
2.00	4.00	5.25	5.50	6.50	8.25		8.25	6.25	5.00	4.00	1.75
1.50	4.00	3.75	4.75	5.00	7.25	8.50	7.50	5.50	3.75	2.50	2.00
1.50	2.50	3.75	4.25	4.75	5.50	6.00	5.50	4.50	3.50	3.00	1.75
1.00	2.50	3.00	3.50	4.00	4.50	5.00	4.50	4.00	3.00	2.00	1.00
0.75	1.00	1.75	2.25	3.50	4.25	4.50	4.00	3.50	1.50	1.00	0.50
0.25	0.50	1.00	1.00	1.50	2.00	2.00	1.50	1.00	0.50	0.50	0.25
0.00	0.25	0.50	0.50	0.50	1.00	1.00	0.75	0.75	0.50	0.25	0.00

Appendix : 14

Table 15. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 0
wind condition   wind speed : 5.978 kmph
riser position : vertical

0.00	0.00	0.50	1.00	1.50	3.00	4.50	3.00	4.00	5.00	4.00	1.00	0.50
0.00	0.00	0.50	1.00	2.50	5.00	5.00	5.00	5.50	5.00	3.00	1.00	0.50
0.00	0.00	0.50	1.00	2.00	4.00	6.00	6.50	6.00	5.00	6.00	5.00	0.50
0.15	0.15	0.50	4.50	4.00	5.00	7.50	8.00	6.00	7.00	6.00	5.00	0.50
0.15	0.25	1.00	3.00	5.00	6.50	7.50	6.00	6.50	6.00	6.00	5.00	1.00
0.25	0.50	2.00	3.50	5.00	6.00	6.50	7.00	5.00	5.00	4.50	4.00	1.50
0.00	0.25	1.00	4.00	5.00	7.50		6.50	6.50	4.50	4.50	3.00	1.50
0.00	0.25	1.00	2.00	5.00	4.50	5.00	5.00	5.50	4.50	4.00	2.00	1.00
[illegible]	[illegible]	0.50	1.50	3.00	2.50	4.00	4.00	3.00	2.50	1.75	1.50	1.00
0.00	0.00	0.25	[illegible]	3.00	3.00	4.00	3.00	2.50	2.00	2.00	1.00	0.50
0.00	0.00	0.00	0.25	3.00	2.50	3.50	1.00	1.00	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.50	3.00	2.00	1.00	0.50	0.25	0.15	0.00	0.00
0.00	0.00	0.00	0.00	1.00	0.25	0.50	0.25	0.15	0.00	0.00	0.00	0.00

Appendix : 15

Table 16. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 2 8'41''
no wind condition
riser position : mid way

0.00	0.00	0.00	0.00	1.00	2.00	2.50	3.00	2.00	1.50	2.00	1.00	1.00
0.00	0.00	0.00	0.50	2.00	3.50	4.00	4.00	4.00	4.00	3.50	3.00	1.00
0.00	0.15	2.00	4.00	4.00	5.00	4.50	2.50	4.00	3.00	3.00	3.50	1.50
0.25	0.25	2.00	4.00	5.00	5.50	5.00	3.50	4.00	4.00	3.00	2.00	1.00
0.50	0.20	1.50	4.50	5.50	5.00	5.50	5.50	5.00	4.00	3.50	2.50	1.50
0.25	0.15	1.50	2.50	4.00	3.00	6.00	5.00	5.00	5.00	4.50	3.00	2.00
0.50	0.10	1.00	3.50	4.00	5.50		5.00	5.00	4.50	4.00	3.50	2.00
0.00	0.00	0.15	0.50	1.00	2.00	1.50	4.00	3.00	4.00	3.00	2.00	1.50
0.00	0.00	0.00	0.00	0.25	0.50	1.00	1.00	2.00	2.50	4.00	1.50	1.00
0.00	0.00	0.00	0.00	0.00	0.15	0.25	2.00	0.50	3.00	1.50	0.15	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.25	0.50	0.25	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.50	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix : 16

Table 17. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 2 8'41''
wind condition   wind speed : 5.48 kmph
riser position : mid way

0.00	0.25	0.50	0.50	0.75	1.00	1.00	1.50	1.50	1.00	0.75	0.50	0.50
0.00	0.15	0.25	0.75	1.00	1.50	2.75	3.00	2.50	2.25	1.50	1.25	0.75
0.15	0.50	1.00	1.50	2.00	3.50	4.75	5.00	4.50	3.50	2.50	2.00	1.00
0.75	0.75	1.50	2.25	3.00	4.50	5.50	5.50	5.00	4.50	3.50	3.25	1.50
0.50	1.00	2.00	2.25	3.75	4.00	6.00	6.25	5.50	4.75	4.00	3.50	1.00
0.25	1.00	1.50	2.50	3.00	5.00	6.00	6.25	5.50	5.00	4.50	3.75	1.50
0.25	0.50	1.75	2.00	3.75	4.50		6.50	5.00	5.25	4.25	3.00	1.00
0.10	0.50	1.50	2.00	2.25	4.75	5.00	5.75	5.00	4.00	3.75	1.25	0.50
0.00	0.25	1.00	1.50	1.75	3.50	4.50	5.50	4.50	3.25	1.25	0.25	0.00
0.00	0.10	0.50	1.00	1.50	1.75	2.00	5.00	3.00	1.00	0.75	0.00	0.00
0.00	0.00	0.15	0.50	0.75	1.00	1.00	2.50	2.00	1.00	0.50	0.00	0.00
0.00	0.00	0.00	0.10	0.15	0.25	0.75	0.50	0.50	0.75	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix : 17

Table 17. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 4 17'21''
no wind condition
riser position : perpendicular

0.00	0.00	0.50	0.75	1.00	1.50	1.50	1.50	1.00	1.00	0.75	0.25	0.00
0.00	0.25	1.50	2.00	2.50	2.75	3.00	2.75	2.00	1.75	1.50	0.50	0.00
0.50	1.50	1.75	2.00	3.50	4.00	5.00	4.00	3.50	2.00	2.00	0.75	0.25
0.50	0.75	1.50	2.00	3.25	4.25	6.50	5.00	4.25	3.50	2.50	1.00	0.50
1.00	2.50	3.50	4.25	5.25	6.00	7.50	6.25	5.00	4.00	3.25	1.75	1.00
1.00	3.25	4.50	5.50	6.00	7.50	8.75	7.25	6.25	5.50	4.25	2.25	1.00
1.50	3.00	5.50	6.75	7.75	8.50		8.50	7.25	6.50	5.25	3.00	1.75
1.50	3.25	4.25	5.25	6.75	7.00	8.75	7.00	6.50	5.50	4.00	3.25	1.50
1.00	1.50	2.50	4.75	4.00	5.00	7.25	6.00	5.00	3.75	3.00	3.00	1.50
0.75	1.75	2.50	3.25	4.25	5.00	6.25	5.25	4.00	3.50	2.50	2.00	1.00
0.50	1.00	1.50	2.00	3.50	4.00	5.25	4.25	3.25	2.00	1.75	1.50	0.50
0.25	0.50	1.00	1.75	2.75	3.00	3.25	3.00	2.50	1.50	1.00	1.00	0.25
0.00	0.00	0.25	0.50	1.00	1.00	1.50	1.00	1.50	0.75	0.75	0.50	0.00

Appendix : 18

Table 19. Quantity of water collected in the catch cans (ml)
slope : 7.5 %   riser angle : 2 8'41''
wind condition   wind speed : 5.318 kmph
riser position : perpendicular

0.00	0.10	0.50	2.00	4.50	3.00	4.00	4.00	2.00	1.50	0.25	0.25	0.00
0.00	0.15	0.15	1.25	3.50	3.00	4.00	5.00	4.00	3.00	1.00	1.00	0.00
0.00	0.25	0.50	1.75	3.25	3.00	5.00	5.50	5.00	4.25	4.00	1.50	0.00
0.00	0.15	0.50	2.00	5.50	5.00	6.50	5.00	5.00	5.00	3.00	1.00	0.00
0.00	0.10	1.00	4.00	5.50	5.00	7.00	5.50	6.00	5.00	3.00	2.00	0.00
0.00	0.00	1.00	4.00	5.00	5.25	7.50	6.50	6.00	6.25	4.00	2.00	0.00
0.00	0.10	0.50	4.00	5.00	6.50		7.50	6.00	6.25	4.00	1.50	0.00
0.00	0.25	0.50	4.00	5.00	5.50	6.00	5.50	5.25	4.75	2.00	1.00	0.00
0.00	0.00	0.15	0.25	4.00	4.50	6.25	5.50	5.00	4.50	2.00	1.00	0.00
0.00	0.00	0.00	0.15	0.25	2.00	3.75	3.50	3.00	4.00	2.50	1.00	0.00
0.00	0.00	0.00	0.00	0.15	0.25	0.50	1.50	3.00	2.50	0.50	0.50	0.00
0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.25	0.50	0.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.10	0.15	0.10	0.10	0.00	0.00	0.00	0.00

APPENDIX : 19

TABLE 20. QUANTITY OF WATER COLLECTED IN THE CATCH CANS (ML)

NO WIND CONDITION NO SLOPE CONDITION

0.50	0.50	0.50	1.00	1.00	1.50	2.00	1.50	1.50	1.00	1.00	0.50	0.50
0.50	1.00	1.50	2.00	2.50	3.50	4.00	3.00	2.00	1.75	1.50	1.00	0.50
0.50	1.00	1.50	3.00	4.00	5.00	7.00	5.50	3.25	2.00	1.50	1.00	0.50
1.00	1.50	3.50	4.00	5.25	6.75	7.50	7.00	5.00	4.00	3.25	1.50	1.00
1.00	3.50	4.50	5.00	6.00	7.50	8.75	7.50	5.50	3.00	2.00	1.50	1.00
1.50	2.50	4.25	6.25	8.00	9.25	9.00	9.00	7.50	5.00	4.00	2.50	1.50
2.00	4.00	5.50	7.00	8.25	9.00		8.75	8.00	7.00	6.00	5.50	2.00
1.00	2.25	4.50	5.50	6.00	8.00	9.00	8.00	6.50	5.50	4.50	2.00	1.00
1.00	1.50	4.50	5.00	6.25	7.00	8.75	7.25	6.00	5.00	4.25	1.50	1.00
0.75	1.00	1.50	2.50	4.25	5.25	7.00	5.00	4.00	2.50	1.50	1.00	0.50
0.50	1.00	1.00	2.00	3.50	4.50	5.00	4.25	3.25	2.00	1.00	1.00	0.50
0.50	1.00	1.00	1.50	2.50	3.00	4.00	3.50	2.00	2.50	1.75	0.75	0.50
0.25	0.50	0.50	1.00	1.00	1.75	2.00	1.50	1.00	1.00	0.50	0.25	0.25

APPENDIX : 20

TABLE 21. QUANTITY OF WATER COLLECTED IN THE CATCH CANS (ML)

WIND CONDITION NO SLOPE CONDITION

0.00	0.00	0.50	1.00	0.75	1.00	1.00	1.00	0.75	0.50	0.50	0.00	0.00
0.00	1.00	1.00	2.00	1.50	2.00	2.50	1.50	0.75	1.25	1.00	0.50	0.00
0.00	1.00	2.50	2.50	4.00	3.00	4.00	3.00	2.50	2.00	1.50	1.50	0.75
0.50	2.00	3.00	3.25	5.50	5.00	6.00	5.25	4.00	3.25	2.50	1.75	0.75
0.75	2.75	4.00	4.50	6.00	7.50	8.00	7.00	6.50	6.50	5.00	3.00	1.00
1.00	3.00	4.00	5.00	6.50	9.00	8.50	9.25	6.00	6.50	6.00	5.00	1.50
0.75	2.50	4.50	6.00	6.00	9.00		9.50	7.00	6.00	5.50	3.75	1.00
1.00	2.00	3.50	3.50	5.00	6.00	7.00	7.00	5.00	3.50	4.75	3.25	1.50
1.50	1.50	2.00	2.50	4.00	4.50	5.00	5.50	4.50	3.00	3.00	2.00	1.00
1.00	0.75	1.50	3.00	3.00	4.25	4.50	4.00	5.00	3.50	2.50	1.50	0.50
0.50	1.00	1.50	2.50	2.75	3.50	3.00	2.50	3.00	1.75	2.00	0.50	0.00
0.00	0.00	0.00	1.00	1.50	1.75	2.50	2.00	1.50	1.50	1.00	0.00	0.00
0.00	0.00	0.00	0.25	0.25	0.50	1.00	1.00	0.75	0.25	0.00	0.00	0.00

R

APPENDIX : 21

TABLE 22. TIME FOR ONE ROTATION OF SPRINKI
RISER POSITION : VERTICAL
NO WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)
1	12.50	38.00
2	12.50	38.50
3	12.50	38.00
1	10.00	37.50
2	10.00	38.50
3	10.00	38.00
1	7.50	37.50
2	7.50	38.00
3	7.50	38.00

APPENDIX : 22

TABLE 23. TIME FOR ONE ROTATION OF SPRINKLI
RISER POSITION : MID WAY
NO WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)
1	12.50	44.50
2	12.50	45.00
3	12.50	45.00
1	10.00	42.00
2	10.00	43.00
3	10.00	41.50
1	7.50	40.00
2	7.50	42.00
3	7.50	41.50

R

APPENDIX : 23

TABLE 24. TIME FOR ONE ROTATION OF SPRINKLER
RISER POSITION : PERPENDICULAR
NO WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)
1	12.50	45.00
2	12.50	50.00
3	12.50	49.00
1	10.00	45.00
2	10.00	47.00
3	10.00	46.00
1	7.50	40.00
2	7.50	43.00
3	7.50	41.00

APPENDIX : 24

TABLE 25. TIME FOR ONE ROTATION OF SPRINKLER
RISER POSITION : VERTICAL
WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)	Wind speed (kmph)
1	12.50	40.00	4.710
2	12.50	43.00	6.282
3	12.50	42.00	6.042
1	10.00	40.00	3.184
2	10.00	41.50	6.150
3	10.00	41.00	5.816
1	7.50	39.00	4.238
2	7.50	40.00	6.978
3	7.50	40.00	6.414

R APPENDIX : 25

TABLE 26 TIME FOR ONE ROTATION OF SPRINKLER
RISER POSITION : MID WAY
WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)	Wind speed (kmph)
1	12.50	50.00	3.954
2	12.50	53.00	5.795
3	12.50	52.00	5.190
1	10.00	45.00	3.957
2	10.00	47.00	7.265
3	10.00	46.00	6.348
1	7.50	44.00	5.480
2	7.50	45.00	6.858
3	7.50	44.50	5.805

R APPENDIX : 26

TABLE 27. TIME FOR ONE ROTATION OF SPRINKLER
RISER POSITION : PERPENDICULAR
WIND CONDITION

Sl No.	Slope (%)	Time for one rotation(sec)	Wind speed (kmph)
1	12.50	53.00	4.320
2	12.50	55.00	6.336
3	12.50	54.50	5.525
1	10.00	49.00	5.992
2	10.00	52.00	7.386
3	10.00	51.00	6.743
1	7.50	43.00	3.450
2	7.50	46.00	4.416
3	7.50	44.00	5.318

APPENDIX : 27

TABLE 28 EROSION MEASUREMENT
RISER POSITION : VERTICAL
NO WIND CONDITION

Sl No.	Slope (%)	Amount of soil collected(gm)	Amount of soil collected/ha(kg)
1	12.50	0.055	11.033
2	12.50	0.060	12.036
3	12.50	0.058	11.634
1	10.00	0.042	8.425
2	10.00	0.045	9.027
3	10.00	0.044	8.826
1	7.50	0.023	4.614
2	7.50	0.025	5.915
3	7.50	[illegible]	5.015

APPENDIX : 28

TABLE 29 EROSION MEASUREMENT
RISER POSITION : MID WAY
NO WIND CONDITION

Sl No.	Slope (%)	Amount of soil collected(gm)	Amount of soil collected/ha(kg)
1	12.50	0.052	10.431
2	12.50	0.054	10.832
3	12.50	0.052	10.432
1	10.00	0.037	7.422
2	10.00	0.040	8.024
3	10.00	0.038	7.622
1	7.50	0.020	4.012
2	7.50	0.023	4.613
3	7.50	0.022	4.413

APPENDIX : 29

TABLE 30. EROSION MEASUREMENT
RISER POSITION : PERPENDICULAR
NO WIND CONDITION

Sl No.	Slope (%)	Amount of soil collected(gm)	Amount of soil collected/ha(kg)
1	12.50	0.046	9.227
2	12.50	0.050	10.030
3	12.50	0.048	9.629
1	10.00	0.030	6.018
2	10.00	0.035	7.021
3	10.00	0.035	7.021
1	7.50	0.015	3.009
2	7.50	0.020	4.012
3	7.50	0.018	3.610

Appendix: 30

Calculation of uniformity coefficient (Table 5)

No. of catch cans = 168

Total water collected = 420.75ml

Mean = $\frac{420.75}{168} = 2.504$

Observation	Frequency	Numerical deviation	Frequency X deviation
0.00	19	2.504	47.58
0.25	9	2.254	20.29
0.50	14	2.004	28.06
0.75	11	1.754	19.30
1.00	15	1.504	22.57
1.25	1	1.254	1.254
1.50	12	1.004	12.05
1.75	4	0.754	3.02
2.00	7	0.504	3.53
2.25	2	0.254	0.51
2.50	3	0.004	0.012
3.00	8	0.496	3.96
3.25	7	0.746	5.22
3.50	2	0.996	1.99
3.75	2	1.146	2.49
4.00	8	1.496	11.96
4.25	3	1.746	5.24
4.50	5	1.996	9.98
4.75	4	2.246	8.98
5.00	10	2.496	24.96
5.50	6	2.996	17.97

6.00	5	3.496	17.48
6.25	1	3.746	3.746
6.50	1	3.996	3.996
6.75	2	4.246	8.49
7.00	4	4.496	17.98
7.25	3	4.746	14.23

$\Sigma X = 316.834$

$$Cu = 100\left(1 - \frac{\Sigma X}{mn}\right)$$

$$= 100\left(1 - \frac{316.834}{2.504 \times 168}\right)$$

$$= 100\,(1 - 0.753)$$

$$= 24.7\%$$

Specification of wind anemometer

Name	-	Anemometer
Model No.	-	252412
Range	-	Km/hr
Supplied	-	Ogawa Secki Co. Ltd. Tokyo, Japan.

Specification of pump

Name	-	Keragro monoset pump
Motor type	-	Capacitor start and run
Phase	-	1
Volt	-	240
Max Current	-	6 Ampere
Speed	-	2820 rpm
Head	-	20 m
Discharge	-	1.5 lps
Overall effiency	-	26 %
Manufactered by	-	Kerala Agro Industries Corporation Ltd., Trivandrum.

Specification of catch can

Diameter of catch can = 10cm

Capacity of catch can = 1 litre

Specification of sprinkler head

Operating pressure	-	1.5Kg/cm^2
Discharge	-	0.092 lit/sec
diameter of coverage	-	12m

EFFECT OF LANDSLOPE ON UNIFORMITY OF WATER DISTRIBUTION OF SPRINKLERS

By

JIGIMON T.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Technology in Agricultural Engineering

Faculty of Agricultural Engineering & Technology

KERALA AGRICULTURAL UNIVERSITY

Department of Land and Water Resources & Conservation Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679 573

MALAPPURAM

1996

ABSTRACT

A study was conducted at Kelappaji College of Agricultural Engineering and Technology, Tavanur to find out the effect of land slope on sprinkler uniformity. A single nozzle sprinkler was used for the study. The study was carried out over an artificial platform. The water distribution pattern for three slopes viz; 12.5 %, 10.0 % and 7.5 % was studied for three riser positions viz; vertical, mid way and perpendicular to the land. Isohytes were drawn for the various positions in wind and no wind conditions for the three slopes. The uniformity cofficient, Cu values were evaluated and the spacing between the sprinklers for good overlap was found out. It is found that the water distribution is decreasing as the land slope is increasing. The perpendicular position was the ideal position for all the slopes. The optimum riser angles for various slopes are found to be 7°7'30''for 12.5 % slope, 5°42'38'' for 10.0 % slope and 4°17'21'' for 7.5 % slope with respect to the vertical position.

The rpm of the sprinkler head for three riser positions was studied. In vetical position the rpm was almost same in all the slopes. It was decreasing as the riser position was changing from vertical to perpendicular in every slope. The rpm was less in wind conditions than in no wind conditions.

The erosivity was also measured. The amount of soil collected for the various positions was evaluated. It was found that the amount of soil loss is incerasing with the increase in land slope. It was maximum in vertical position, less in mid way position and least in perpendicular position for all the land slopes.