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Evaluation of a Traveller Sprinkler System with Various Nozzles

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Abstract

Global climate change and its effect on water resources have further reduced the amount of water available for agriculture. Under this circumstance, the use of pressurized irrigation systems can be an option of enhancing the efficiency of water consumption. The mobile rain gun is very useful equipment which can be used for irrigating large areas and it works at a minimum pressure of 2kg/cm². The mobility of the equipment is possible at minimum pressure of 6kg/cm² pressure. For the calculation of uniformity in irrigation catch can test were conducted at various pressure by using various nozzle. The Christiansen's equation for uniformity was used for calculation purpose. The grid is plotted for the spacing 3x3 meters and it covers an area of about 360m². The maximum uniformity was noted in the 12mm nozzle at 2kg/cm² pressure. The uniformity is much reduced for the high pressure due to wind drift and pressure fluctuations. The contour graphs were also used to find out the area of highly uniform distribution. The tape was used for measuring the throw range of rain gun during operation. The throw range varies from 8 to 30m for 10mm at 2kg/cm² and 14mm at 6kg/cm² respectively. The distribution graph was drawn to find out the change in distribution of water along with the change in distance from the rain gun. The rain gun is designed to irrigate large area by using a single unit so the distribution is more for large ranges compared to the places which are nearer to the implement. One of the major problem occur during the sprinkler irrigation is evaporation loss of spraying water. The distribution of water depended upon the things like pressure, climatic condition, wind speed, wind direction and the temperature.

Keywords: Distribution Uniformity; Christiansen; Mobile Rain Gun; Pressurized Irrigation.

INTRODUCTION

Land and water are the major factors for the progress of agriculture. In a vast country like India with a geographical area of 328 million hectares less than 45% area is cultivated. Of this cultivated area only 35% i.e. 65 million ha gets irrigation. Since water is the limiting factor today, we must utilize it properly and maximum benefit can take as possible as India is second largest country in world according to population, 1202 million. The expansion of area under irrigation is essential for obtaining increased agriculture production required to feed India's growing population. The expansion could be done only by additional development conservation and efficient management of the available water resources i.e. use of micro-irrigation means application of optimum water according to plant requirement. This could be achieved by introducing advanced and sophisticated methods of irrigation viz. drip irrigation, sprinkler, etc. which is also called as micro irrigation methods.

Micro irrigation is a modern method of irrigation by this method water is irrigated through drippers, sprinklers and by other emitters on surface or subsurface of the land. It helps to overcome draught and water scarcity. This can be possible by means of gravity and pressurized methods, i.e. with or without the use of pump. The major components of a micro irrigation system are water source, pumping devices

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(motor and pump), ball valves, fertigation equipment, filters, control valves, PVC joining accessories (Main and sub main) and emitters. Drip irrigation is not suitable for undulating and high elevated lands so in that type of areas instead of drippers sprinklers are using. Sprinklers cover more area in short time it needs minimum 1.0kg/cm² pressure which covers about 12m dia.

Sprinkler irrigation is mostly followed in sandy or loamy soils. It is the method applying water to a controlled manner similar to rainfall. This system is most suitable to horticultural crops and small grasses. Sprinklers is available in various types like rotary head sprinklers, portable micro sprinklers, rain guns etc. They distribute more water than drippers and micro sprinklers. Various types of nozzles are available for multipurpose. High pressure sprinklers that themselves move in a circle are driven by a ball drive, gear drive or impact mechanism. These can be designed to rotate in a full or partial circle. Rain guns are similar to impact sprinkler, except that they generally operate at very high pressure of 275 to 900kPa and flows of 3 to 76L/s, usually with nozzle diameters in the range of 0.5 to 1.9inches.

Irriforce is an irrigation machine designed for Energy Efficiency. Its cost in terms of both use and investment is lower than those of its rivals. We may call Irriforces as traveling rain gun. Thanks to water turbine and steel rope in it, it irrigates your field by dragging itself. Irriforces can be used in anywhere irrigation is required; you may conveniently use it for irrigation of any agricultural products, any sport sports grounds, lawn irrigation, meadow irrigation and range improvement. Most important factor making such small dimensions of irriforces is that it is equipped with soft hose. Testing is essential to find out the various efficiency of mobile sprinkler. Catch can test is the one and only testing universal testing machine. It helps to measure the health and performance of irrigation systems. It provides results with distribution uniformity and precipitation rate. Distribution uniformity indicates how uniformly water is distributed in the given area at specific point of time. The water captured in the catch cans can be measured in millimeters. The test was conducted during morning and afternoon.

LITERATURE REVIEW

To sustain agricultural production in the coming years, it is important to optimize irrigation systems adjusting water application to crop water requirements. This will help protect both the quantitative and qualitative aspects of water conservation (Delirhasannia et al., 2010). Although, irrigation increases the yield (Al-Mefleh and Tadros, 2010); it may also generate significant expenses (Tanasescu and Paltineanu, 2004). To decrease overall crop production costs, but also to provide better conditions for achieving the sustainability of agricultural production, losses in water distribution networks have to be carefully evaluated and minimized (Sourell and Muller, 2003;Tabesh et al., 2009). The crop water use efficiency has been shown to depend on irrigation amount and frequency. Tillage practices can also influence the water use efficiency for a given irrigation frequency (Adekalu, 2006). The irrigation number, amount and uniformity of water application are used mainly to determine the efficiency of irrigation scheduling. Excessive doses of infrequently applied water will lead to high percolation losses.

A possible approach, among many others, is to develop irrigation systems characterized by the water deposit distribution as evenly as possible (Sourell and Sommer, 2000). Furthermore, starting from the water–yield relationship (Oktem et al., 2003; Dagdelen et al., 2006; Payero et al., 2006; Kiziloglu et al., 2009), an optimal time schedule of irrigation water quantity has to be established using various optimization criteria and methods (Kuol and Liu, 2003; Lohani et al., 2004; Sahoo et al., 2006). Wigginton and Raine (2001) reported inappropriate uniformity of water distribution provided by travelingrain guns, which varied in extremely wide range: from 1% and up to 88% of nominal value, having average value of 62%. In addition, only two of eight tested machines achieved water deposition uniformity over 80%. Smith et al. (2008) have developed special simulation software which provides useful information on the water deposition uniformity of a rain gun depending on wind velocity and direction. They stated that simulation enables evaluation of raining tracks distance and concluded that water deposition between two tracks varies between 0 and 39.5 mm. In their experiment, they used data obtained from several stationary rain-meters placed on every 5m along the rain-gun width. The data were collected for different wind speeds varying from 0.68 to 3.66 m/s. To meet specific requirements of different crops, climate and soil conditions, as well as the applied growing technology, different types of irrigation systems have been developed and applied (Dragović, 2000). Although, some sophisticated and highly economical techniques like surface and subsurface drip irrigation systems have been designed during the past few decades (Ayars et al., 2001; Hanson and May, 2004; Barragan and Wu, 2005; Kalfountzos et al., 2007); classic mobile sprinkler irrigation systems still have dominant role in vegetable and crop production. Among them, a traveling rain gun represents a possible farmers' choice for mechanized irrigation (Miodragović, 2001).

Most irrigation systems are suitable for the rectangular and square irrigation surface. The system adaptability depends on the type of irrigation system movement, construction flexibility and the number of sprinklers. Traveling rain gun is very flexible in comparison to the center pivot irrigation device. Utilization of the irrigation surface with these systems is 60% (Miodragović, 2009), but it can be decreased if the shape of the irrigated field is more different than the square. However, as it is also the case with other irrigation systems, the use of traveling rain gun is commonly followed by many problems related to optimum choice of the rain gun model and type, adequate adjustment of working parameters and maintenance, efficient control, continual monitoring etc. In general, an irrigation system should provide uniform water deposition in the longitudinal and lateral direction, equal to irrigation norm, defined for each specific period over a year. The travelling big gun system uses a large-capacity nozzle and high pressure to throw water out over the crop as it is pulled through an alley in the field. Travelling big guns come in two main configurations: hard-hose or flexible-hose feed. With the hard-hose system, a hard polyethylene hose is wrapped on a reel mounted on a trailer. The trailer is anchored at the end or Centre of the field. The gun is connected to the end of the hose and is pulled towards the trailer. The gun is pulled across the field by the hose winding up on the reel. With the flexible-hose system, the gun is mounted on a four-wheel cart. Water is supplied to the gun by a flexible hose from the main line. A cable winch pulls the cart through the field towards the cart.

MATERIALS AND METHODS

Irriforce is an irrigation machine designed for Energy Efficiency. Its cost in terms of both use and investment is lower than others. It is also called as travelling rain gun. Irriforces can be used in anywhere irrigation is required like irrigation of any agricultural products, any sport sports grounds, lawn irrigation, meadow irrigation and range improvement. Most important factor making such small dimensions of Irriforces is that it is equipped with soft hose. It only pulls its special hose equivalent to ¼ of its own weight, instead of dragging tons of pipes in weight. And thus energy efficiency maximizes. Higher weight pulled would also affect service life of your machine. And storage and handling costs are also small.

There is 5-hp energy difference between delivery of water at 30m^3/hour at 7 bar (pumping) and at 8 bar (pumping). Here 5-hp means spending more diesel up to 1.5 litre. There are different types that can irrigate up to 100 m – 130 m – 200 m -300 m and 400m in length. Water of minimum 12m3/hour should be delivered through hydrant at 4 bar. It operates with water of maximum 30m3/hour. When the irrigation gun revolves one full turn, its effective irrigation distance is maximum 250 meters. Maximum irrigation depth is 60 meters. It is mostly preferred by those who want to irrigate agricultural farms, meadows and pasture alfalfa. It may also be used for irrigation of any type of agricultural fields. It may be used as washing gun to remove dust and dirt off the plants in the fields of alfalfa, vegetables, corn, sugar beet, sunflower and olive trees where drip irrigation is used and as support irrigation when irrigation by dipping proves to be insufficient. Minimum recommended pumping power is 7.5 HP.

IrriforceMidi TD2000-200 is one of the irriforce models as shown in Fig. 1. Water of minimum 12m3/hour should be delivered through hydrant at 4 bar. It operates with water 8.5 to 30m3/hour. It has JET40 irrigation gun on it. Maximum travelling distance is 200 meters. When the irrigation gun revolves one full turn, its effective irrigation distance is maximum 250 meters. Maximum irrigation depth is 60 meters. It is mostly preferred by those who want to irrigate agricultural farms, meadows and pasture alfalfa. It may also be used for irrigation of any type of agricultural fields. It may be used as washing gun to remove dust and dirt off the plants in the fields of alfalfa, vegetables, corn, sugar beet, sunflower and olive trees where drip irrigation is used and as support irrigation when irrigation by dipping proves to be insufficient. Minimum recommended pumping power is 7.5 HP. Pull-type hose drum manually winding also comes with the machine. Hose drum wound by tractor shaft may be obtained optionally.

Rotatable sprinkler heads with gearbox and adjustable for full or part circle coverage, featuring medium and high pressure operations, and high efficiency. This model is an introduction to the professional series. Changeable nozzles and dynamic water jet breaker system enable a perfect irrigation with evenly distributed water. Suitable for using in any type of delicate or rough agricultural applications; widely used especially on wheat, maize, and clover. Makes full and semi-circle turns at the same speed; ideal for agricultural areas, sport fields, and mines; suitable for portable and fixed systems. Range of usable nozzle diameter is 10 to 20mm, water consumption is – 6.5 to 44m^3/h and shooting are –19 to 43m.

Fig. **1.** Traveller Rain Gun (Sprinkler System).

TESTING METHODS

Uniformity testing: Catch-cans method

This is a method of measuring the uniformity of sprinkler by using the cans. This is a universal field test for uniformity identification.

Formula for finding the uniformity of sprinklings

$$CU = 100 \times \left(1 - \frac{\sqrt{\frac{\sum_{i}^{n}(z-m)^2}{n}}}{m} \right) \quad (1)$$

N= total number of cans

Zi= Volume of water applied at the location of each can

M= mean of water applied in all location of cans

Procedure for catch- cans method

- Approximately 50ml catch cans are kept in field on 2m×2m grid.
- Operate the sprinkler for specified amount of time.
- Find out the area of the opening of the can
- Divide the volume of water collected by the area of opening of the can to get the depth of water applied at each can.
- If the uniformity values obtained from the formula is above 80%, then the design of installation is said to be satisfactory.

Irrigation efficiency

Efficiency is the ratio of the water output to the water input, is usually expressed as percentage. Input minus output is loss. Hence the efficiency is directly proportional to the loss. This efficiency is influenced by evaporation, water seepage, etc.

Performance test

Measurement of pressure

- A pressure gauge, calibrated in psi, was installed on the supply line of the raingun to measure pressure.
- Another pressure gauge was installed in the pump control room near the well to regulate pressure. The required pressure was obtained by using a bypass system.
- When the required pressure was obtained, the raingun system was started.
- The pressure was again checked with the help of the pressure gauge installed on the supply line of the raingun.
- The required pressure was maintained throughout the operation of raingun for to complete each data set

Discharge

Discharge of an irrigation system is obtained by connecting flexible tubes on the sprinkler nozzle and collecting the discharge in a container in a specified period.

- **Measurement of discharge**
  - ✓ A water meter of 50-mm diameter was installed on the supply line to measure quantity of water entering into the raingun sprinkler irrigation system. The water meter was calibrated in cubic meters.
  - ✓ Before starting the system, initial meter reading was recorded.
  - ✓ After completion of each data set, the final meter reading was again recorded.
  - ✓ The difference in final and initial meter readings gave quantity of water applied through the raingun sprinkler irrigation system.
  - ✓ Discharge of the raingun at a given pressure was estimated by dividing quantity of water with duration of irrigation.

Relation between pressure and discharge.

The discharge is directly proportional to the pressure in the supply line. By calibrating the supply line pressure we can able to measure the discharge by using this formula.

$$Q = 1.947\, H^{0.561} \quad (2)$$

Where;
Q - Discharge of the rain gun,
H – Pressure

Evaporation loss

It is obtained by calculating the difference between discharge and quantity of water in catch cans for specified period.

$$EL = \text{Discharge} - \text{Quantity} \quad (3)$$

Testing has been done at different pressure levels and different nozzle size. Thus, the water distribution level varies at different pressure and nozzle. The results are given in the form of tabulation. The nozzle size is 10,12,14 and measured at 2,4,6 kg/cm². 50 catch cans are placed at a distance of 3m×3m and then its uniformity is measured. Other than its uniformity, its discharge also measured to find the efficiency of travelling raingun. Its uniformity is measured at 360 degree on a full rotation of a raingun. Area is divided into 4 sections and then readings are noted as shown in Fig. 2.

The catch cans are arranged in 3x3 m grid which consist of 6 rows and 9 columns then it covers about 360m² area. The equipment is operated for 15mins then measure the volume of water collected in each catch cans by using measuring cylinder. Then the readings are noted and converted into volume of water per min. During the time of calculation the readings are arranged in ascending or descending order to find the mean deviation. Then by using Christiansen's formula, we get uniformity in percentage at the range between 30-100%.

Calculation of coefficient of uniformity (Cu)

The coefficient of uniformity is calculated by using the Christiansen's equation. The calculations have done in Microsoft excel by importing the catch cans readings from uniformity testing. The coefficient of uniformity for four section of 10mm nozzle at 2kg/cm² pressure, then the average uniformity for this nozzle is about 77.79%. The wind drift and evaporation is less compared to high pressure nozzles. The coefficient of uniformity for four section of 10mm nozzle at 4kg/cm² pressure, then the average uniformity for this nozzle is about 70.14%. The wind drift and evaporation is more compared to 2kg/cm² pressure. The coefficient of uniformity for four section of 10mm nozzle at 6kg/cm² pressure, then the average uniformity for this nozzle is about 59.25%. The wind drift and evaporation is more compared to low pressure nozzles. The coefficient of uniformity for four section of 12mm nozzle at 2kg/cm² pressure, then the average uniformity for this nozzle is about 84.25%. The wind drift and evaporation is less compared to high pressure nozzles. The coefficient of uniformity for four section of 12mm nozzle at 4kg/cm² pressure, then the average uniformity for this nozzle is about 86.31%. The wind drift and evaporation is more compared to 2kg/cm² pressure.

The coefficient of uniformity for four section of 12mm nozzle at 6kg/cm² pressure, then the average uniformity for this nozzle is about 67.66%. The wind drift and evaporation is high compared to low pressure nozzles. The coefficient of uniformity for four section of 14mm nozzle at 2kg/cm² pressure, then the average uniformity for this nozzle is about 66.15%. The wind drift and evaporation is less compared to high pressure nozzles.

The coefficient of uniformity for four section of 14mm nozzle at 4kg/cm² pressure is about 79.80%. The wind drift and evaporation is more compared to 2kg/cm² pressure. The uniformity is different for different nozzles and different pressures. The catch can readings itself shows a drastic change in quantity of water collected during operation. The below mentioned table shows the range of water collected in each catch cans from lower to higher levels. The maximum variation is occurred for the 14mm nozzle with 2kg/cm² pressure. The variation is occurred due to the wind drift and pressure fluctuation in the pipe lines for various discharge. This nozzle with stand the wind drift to an extend and also the uniformity is more compared to the other nozzle sizes.

Uniformity- contours

These are the contours which indicate the uniformity in distribution while the irrigation process is carried out. The contours are drawn for the catch cans readings for various nozzle at various pressures. This is drawn by using Autocad civil 3d software as shown in Fig. 3. This is one of the outputs for the catch cans test which is conducted to find the uniformity of a micro irrigation system.

Calculation of discharge, throw range and area of coverage

Discharge of an irrigation system is obtained by connecting flexible tubes on the sprinkler nozzle and collecting the discharge in a container in a specified period. The throw range is measured distance from center of irrigation nozzle to the end point the water reaches by using tape. Table 1 presents the area coverage for different nozzles at varying pressures.

Calculation of evaporation loss

It is obtained by calculating the difference between discharge and quantity of water in catch cans for specified period as presented in Table 2. The evaporation loss depends upon the temperature and wind characteristics in the testing field.

Estimation of cost

The cost estimation is carried out to find out how effectively the equipment satisfy the farmer economically and also it gives the answer for the question if it is economically affordable for the farmers. Here we are comparing the cost of operation of traditional open channel irrigation and the irriforce irrigation technique. Table 3 presents the cost estimation for open channel irrigation for one acre area.

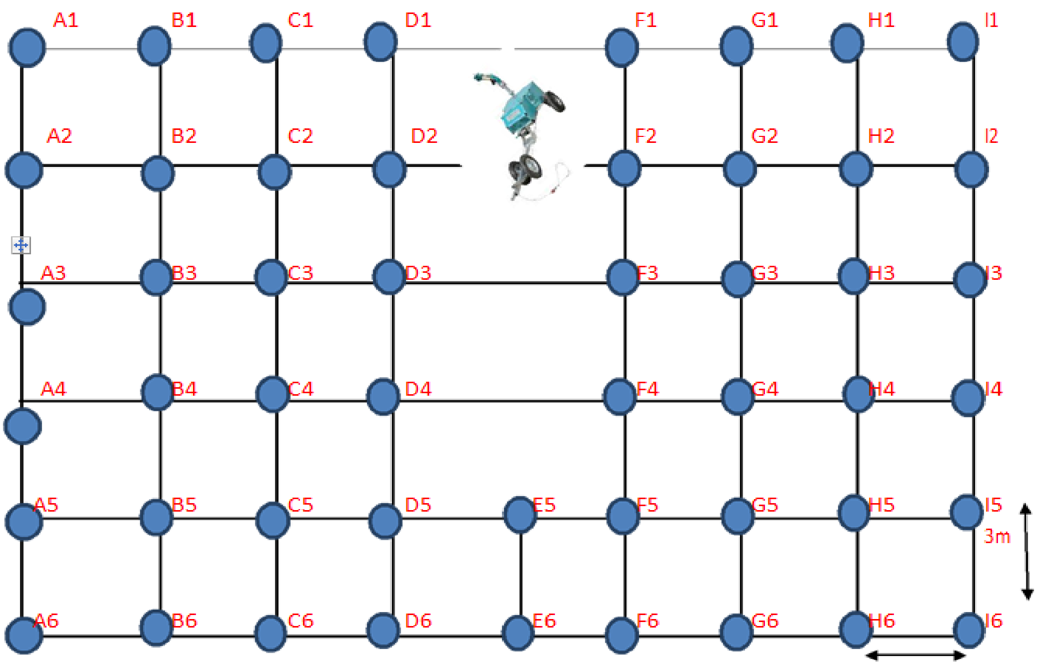

Fig. 2. Schematic test layout setup & Catch cans layout points.

The estimated cost for the open channel irrigation is about Rs.5400 if it is done by the human labour by using equipment like spade. The energy consumption is varying based on the motors or pumps used.

Compared to open channel irrigation the cost demanded for the irriforce is less (Rs.1300) as shown in Table 4. But the initial investment is more compared to others, it is around 2.5 lakhs. So it cannot be preferred by the small scale farmers, for larger area it is beneficial compared to other irrigation practices.

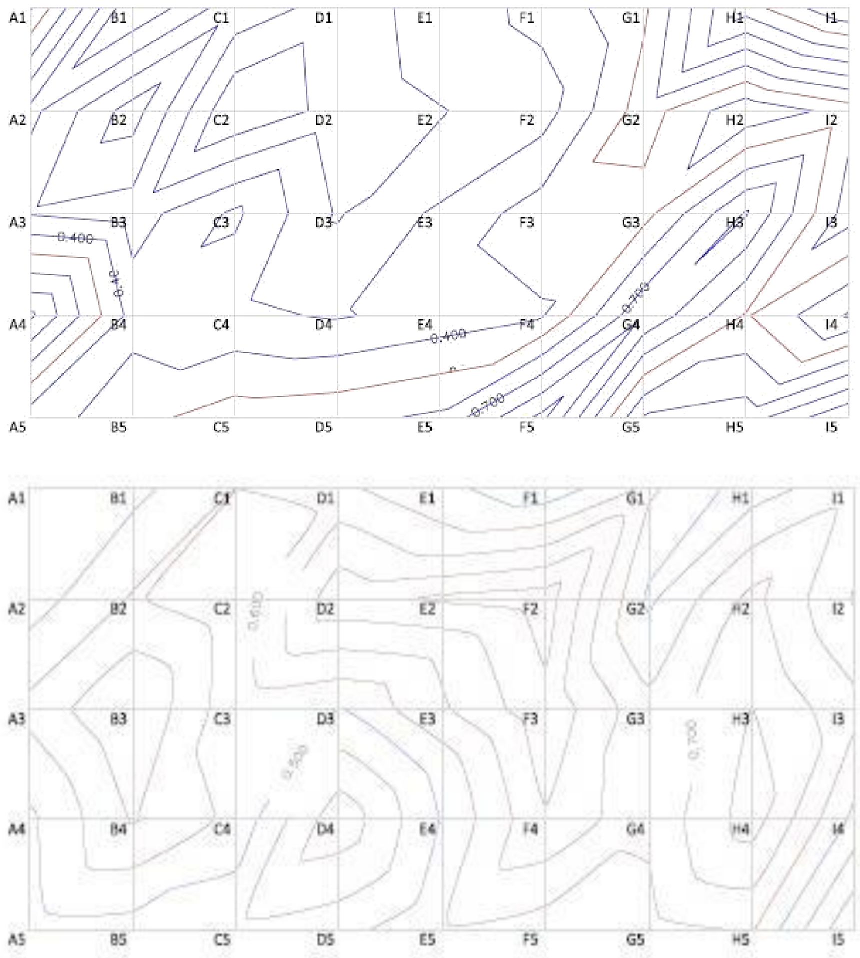

Fig. 3. Uniformity contour map of nozzles with varying pressures

Table 1. Area of coverage for different nozzles at varying pressures

Nozzle size (mm)	Pressure (kg/cm²)	Throw range (m)	Flow rate (l/min)	Area of coverage (m²)
	2	8	60	201
10	4	18	124	1017
	6	24	180	1809
	2	10	80	314
12	4	21	165	1385
	6	26	240	2123
	2	13	95	531
14	4	25	200	1963
	6	30	300	2826

Table 2. Calculation of evaporation loss

Nozzle size (mm)	Pressure (kg/cm²)	Discharge (l/min)	Volume of water in catch cans (ml)	litres	Area (m²)	Quantity of water (Liters)	Evaporation loss (%)
10	2	60	49.74	0.05	201	10.00	39.17
	4	124	37.38	0.04	1017	38.02	69.34
	6	180	34.11	0.03	1809	61.70	65.72
12	2	80	47.04	0.05	314	14.77	68.75
	4	165	48.05	0.05	1385	66.55	59.67
	6	240	46.21	0.05	2123	98.10	59.12
14	2	95	47.16	0.05	531	25.04	73.64
	4	200	47.43	0.05	1963	93.11	53.45
	6	300	42.21	0.04	2826	119.2	60.24

SUMMARY AND CONCLUSIONS:

The travelling rain gun works at minimum 2kg/cm² pressure. It is the lowest possible working pressure. The mobility is possible at minimum 6kg/cm² pressure. For the calculation of uniformity in irrigation catch can test were conducted at various pressure by using various nozzle. The Christiansen's equation for uniformity was used for calculation purpose. The grid is plotted for the spacing 3x3 meters it covers about 360m² area. The maximum uniformity noted in the 12mm nozzle at 2kg/cm² pressure (avg of four sections-86.31). The uniformity is much reduced for the high pressure due to wind drift and pressure fluctuations.

The uniformity graphs are drawn in figures 2. and 3 for the visual representation of uniformity by using the catch cans readings. The contour graphs also used to find out the area of highly uniform distribution. The tape is used for measuring the throw range of rain gun during operation. The throw range varies from 8 to 30m for 10mm 2kg/cm² and 14mm 6kg/cm² respectively. The distribution graph drawn to find out the change in distribution of water along with the change in distance from the rain gun. These rain guns are designed irrigate large area by using a single unit so the distribution is more for large ranges compared to the places which is nearer to the implement. One of the major problem occur during the sprinkler irrigation is evaporation loss of spraying water. It is depended upon the things like pressure, climatic condition, wind speed, wind direction and the temperature. For the high pressure more discharge nozzle the evaporation loss also maximum, here it is 73.86%. To overcome this drawback it is necessary to irrigate at early morning or late evening because at that time the temperature wind effects are very low.

Cost of operation is less for a travelling rain gun when compared to the flood irrigation, but the initial cost is high so it cannot be preferred by the small scale farmers. Hence, this equipment is more efficient at its operation only at the specified conditions.

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